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

Contents

Executive Summary

The success of the research community in addressing the natural dimensions of climate change (as documented in IPCC Assessments) implies that many of the primary questions confronting society with regard to climate change are issues of economics and ethics, rather than natural science.

This chapter frames the economics and ethics of climate change. The significance of economics to solving the climate change problem is self-evident: central to the politics of taking action on climate change are disagreements over the economic costs of action and inaction.

Decision-makers and the public are concerned with what ought to be done about climate change, even though reasonable people have differing views on this issue. What ought to be done, at least in a context that involve values and human interests, is the subject matter of ethics. A contribution of this chapter is in reviewing how the literature views this question.

The way in which one frames the problem of climate change from an ethical perspective and thus what responses can be considered ethically adequate necessarily relies upon answers to normative questions including the following:

What duties do present generations have towards future generations in view of the fact that present emissions affect environmental conditions in the future, and consequently the quality of life of future generations?

Once an intergenerationally just emissions trajectory has been determined on the basis of the duties of present generations towards future generations, a further question is how the responsibility to reduce emissions ought to be allocated among the states (and, ultimately, the individuals living) on this planet?

For those who suffer disproportionally from the consequences of climate change, how can we view their claims to compensatory measures against those who are the main causers or beneficiaries of climate change?

Is the significance of past emissions and their consequences to be understood in terms of compensatory justice, namely as a matter of allocating duties to provide measures of compensation for harm suffered owing to climate change, or in terms of distributive justice, namely as a matter of fairly distributing emission rights among present generations, or in terms of both ?

Justice concepts can roughly be divided into procedural justice and distributive justice. For procedural justice, it is the process of attaining an outcome which governs justness; for distributive justice, it is the actual outcomes which determine justness.

Under the two primary legal systems in the world (common law and civil law), responsibility for harmful actions is generally a basis for liability only if the actions breach some legal norm such as negligence or nuisance. Negligence is based on the standard of the reasonable person. Nuisance liability does not exist if the actor did not know or have reason to know the effects of its conduct.

Common law and civil law differ, but both would require inquiry into whether emission of greenhouse gases falls into a defined category of wrongful conduct. If some or all past emissions satisfy that standard, the next issue in both common law and civil law countries would be the nature of the causal link with the resulting harm *(high confidence).*

The methods of economics provide an anthropocentric measure of value to individual human beings. But climate change also affects important cultural and social values, which can be important in decision making. A social welfare function is an aggregate measure of the wellbeing of members of a society. It gives a basis for evaluating the effects of climate change and of mitigation measures, through economic techniques such as cost-benefit analysis. Different social welfare functions reflect different views about the value of equality.

In cost-benefit analysis, the effect of a change in social value at a time is found by taking the monetary value of the change to each person, weighted appropriately, and adding up these weighted amounts. The weights – often called 'distributional weights' – are the marginal utility of money to an individual multiplied by the marginal social value of the individual's utility: an empirical factor multiplied by an ethical factor. Both utilitarianism and prioritarianism imply that the better off a person is, the lower the weight that should be attached to her monetary values.

Much practical cost-benefit analysis values costs and benefits according to monetary values, added up without any weighting factor. This is to assume implicitly that the distributional weight is the same for each person. This approach could lead to serious error in cost-benefit analysis concerned with climate change, which often needs to take into account the extremes of wealth between rich and poor countries, as well as within countries *(high confidence).*

Discounting allows economic costs and benefits incurred at different points in time to be compared. The relative valuation of economic and environmental assets with respect to time is crucial to decisions on how much sacrifice should be done today for the benefit of future generations.

The discount rate may be viewed from a normative and from a positive perspective. The normative perspective involves determining what discount rate should be used for making long term decisions with regard to climate. The positive perspective focuses on how individuals and markets actually make intertemporal decisions, as revealed by the market interest rate. Both approaches can be relevant, depending on the application.

Using the Ramsey Rule, normatively determining a social discount rate involves making assumptions about the pure rate of utility time preference, the stability of preferences over long spans of time, the growth rate of consumption and aversion to inequality. A selection of typical analyses in the literature presented in the chapter implies a discount rate between 1.4% and 7% per annum. From a positive perspective, the real return on bills and bonds in a selection of North American and European countries from 1900 to 2006 suggests range of real returns from -3.8% to +6.6% annually *(medium confidence).*

There is a great variety of policy instruments to address climate change mitigation. Governmental authorities can use economic, regulatory and informative incentives to support, affect or prevent social change in the context of climate change. There is no 'one-fits-all' type of policy instrument. Neither theory nor experience shows 'one-single' best policy choice. In reality, a mix of policy instrument is the norm. Several policy objectives often require a portfolio of policy instruments but synergies, overlaps, and potentially problematic interactions need careful attention.

Four major categories of objectives of any mitigation policy are economic efficiency, distribution of costs and benefits (burden), environmental and institutional feasibility. These are similar to the main policy objectives in AR4.

Within any given country, carbon policy can have multiple objectives. Besides the reduction of greenhouse gas emissions, it might be intended to achieve other environmental objectives as well as economic, distributional, and institutional objectives. Thus, the evaluation of alternative policies can be conducted relative to those four major categories of objectives: which policies best achieve environmental objectives while minimizing a combination of economic costs and distributional and political disruptions. But each country may attach different relative weights to those objectives, and so each may legitimately chose a different type of policy for itself, to achieve its own GHG emissions target.

Reducing GHG is not totally a technological issue. In fact, behavioral changes and substitutions choices frequently are a major way in which GHG emissions are reduced. Whatever their form, these changes will lead to changes in wellbeing. As with other economic measurement, the changes in wellbeing are measured conceptually by the change in income that is equivalent in terms of the impact on the actor's wellbeing using the WTP or WTA measures.

The Marginal Abatement Cost (MAC) curve, exhibits the aggregate (typically economy-wide) relationship between tons of emissions abated and the marginal cost of abatement (specifically, the equilibrium price of emissions). Under simplified conditions, the area under this curve provides an estimate of total cost of abatement, but it does not capture some of the economy-wide effects associated with existing distortions. Examples are shown in the Chapter.

Some estimates of mitigation costs involve negative marginal costs – one actually saves money by reducing carbon emissions. Whether such negative cost opportunities exist has been much debated. It may be that the estimates of negative costs are flawed – in the field, the savings may not be as large or the costs as low as estimated. Or indeed there may be such negative cost opportunities *(low confidence).*

A number of methods have been developed for dealing with tradeoffs in mitigating different greenhouse gases (eg, methane and carbon dioxide). Most methods are simplifications, for very practical reasons; yet such simplifications can lead to biases.

Aggregate measure of the economic damages of climate change, embodied in many integrated assessment models, may have serious flaws due to oversimplification and aggregation.

There is some evidence that consumers "undervalue" energy costs when the purchase energy-using equipment. Aside from carbon prices, other non-price interventions can reduce energy demand and therefore carbon emissions *(medium confidence).*

Several countries (such as Bhutan and Bolivia) have embodied concepts in their constitutions emphasising an attitude towards nature, where all life is seen as integral.

Meeting aggressive emission reduction targets will be difficult without major changes in the technology of producing and consuming energy. Markets, left to their own devices, will underprovide technological change, even in the presence of a carbon price. Studies suggest that environmental and technology policies work best in tandem.

3.1 Introduction

Over the past few decades, the primary issue in the climate debate has been whether or to what extent human activities are responsible for climate change. This is fundamentally a natural science question. In recent years, as documented in IPCC assessments (particularly AR4), that issue has been largely resolved. As peoples and countries around the world grapple with actions to address climate change, the primary focus has shifted to finding solutions that are both just and cost effective. Thus it could be argued that today, the primary questions confronting society with regard to climate change are issues of economics and ethics, not natural science.

This chapter frames the economics and ethics of climate change. The significance of economics to solving the climate change problem is self-evident: central to the politics of taking action on climate change are disagreements over the economic costs of action and inaction. Within a country, there is great uncertainty regarding (1) the costs of reducing emissions of greenhouse gases, (2) the risks of damage from a change in the climate, and (3) the cost, practicality and effectiveness of adaptation measures. Prioritizing action on climate change vs. acting on other worthy societal goals is difficult in all countries, but particularly so in developing countries where eradicating poverty and achieving social development are high priorities.

One might ask why there is a discussion of ethics in an IPCC assessment. The answer is simple. Decision-makers and the public are concerned with what ought to be done about climate change, even though reasonable people have differing views on this issue. What ought to be done, at least in contexts that involve values and human interests, is the subject matter of ethics. The contribution this chapter makes is in reviewing how the literature views this question.

The ethics of climate change is concerned with promoting values of different sorts, including the wellbeing of individual people. It is also concerned with fairness among people. From a practical point of view, fairness is a central issue when decision-makers try to develop solutions to the climate problem. For instance, within a country, there is the question of the appropriate way of trading off costs and damages that may accrue to different subgroups of the population and at vastly different times (e.g., residents of today vs. those in the year 2100). This issue may involve questions of historical responsibility for past emissions, sharing of the costs of adaptation and coping with climate related weather events, sharing of responsibility for reducing present and future emissions, and equity in the financing of climate related actions and access to technology. Developing real policy solutions inevitably involves creating efficient, just and fair policy solutions.

Questions of ethics are typically normative; questions of economics may be either positive or normative. Positive questions are essentially value-neutral, such as how firms have reacted in the past to cap-and-trade programs for limiting emissions or how law has, historically, treated responsibility for actions that were not yet known to be harmful. Normative questions involve using economics and ethics to answer questions of what *should* be done, such as what is the appropriate level of mitigation or what is the appropriate burden sharing among countries for future mitigation. This chapter does not attempt to answer normative questions, but rather provides policymakers with the tools (concepts, principles, arguments and methods) to make such decisions using their own values. In other words, the chapter is intended as a resource for policymakers and researchers who are trying to solve normative questions. In that sense, the chapter is policy-relevant but not policy-prescriptive.

The next section of the chapter (3.1) provides an introduction to the ethical and socio-economic concepts and principles relevant to climate change that are examined in sections 3.2 to 3.6. Specifically, section 3.2 reviews theories of justice, particularly as relevant to climate change. This includes inter-generational and intra-generational justice, the treatment of historic responsibility, and the separate notions of procedural vs. criteria-based justice. Section 3.3 takes the logical next step and asks how one can value actions that bear on climate change. This includes human values (wellbeing and cultural values) and non-human values. In section 3.4, the question of the distinction between social value and individual value is raised, particularly in the context of aggregating value across individuals and across time. Aggregating value across time is further explored in section 3.5 with a discussion of discounting future goods. The implications of these issues for climate change are reviewed in section 3.6.

In section 3.7 we introduce regulatory mechanisms for achieving mitigation of greenhouse gases and in section 3.8 we discuss methods for evaluating such regulations. In section 3.9 we review the measurement of the costs and benefits of mitigation, including developing tradeoffs in mitigating different greenhouse gases. Section 3.10 introduces issues of behavioral economics and culture into making decisions about mitigation. In section 3.11 we review what is known about the economics of technological change, including ways of inducing additional change to reduce the costs of mitigating greenhouse gas emissions. We conclude (section 3.12) with a discussion of research needs.

3.2 Ethical and socio-economic concepts and principles

Agents of many types can or should take account of climate change in their decision making, including individuals planning their own lives, public and private organizations of all sizes, governments and the international community. Decision making by all these agents raises two distinct ethical questions: by what process should the decision be made, and what should its outcome be? Ethics has the task of assessing both processes and outcomes.

Ethical criteria for making these assessments can be broadly classified into two sorts: criteria of justice and criteria of value. The division between justice and value is not sharp. For instance, justice is clearly a good thing, so it may be included as one value among others. Nevertheless, the broad division between justice and value is a useful basis for organizing the discussion of ethical concepts and principles, and we have adopted it in this chapter. We treat fairness as a part of justice.

Justice and fairness are important criteria in assessing decision-making. In particular, there are issues of distributive and compensatory justice involved in the distribution of costs and benefits between generations and also among people and nations at a single time. The question of historical responsibility for climate change is central among them. All these issues occupy sections 3.2.1 to 3.2.5. Section 3.2.6 considers how far legal thought can contribute to our understanding of historical responsibility. The ethical assessment of the decision-making process (as opposed to outcomes) is treated in section 3.2.7. We concentrate on public-decision making, so the process is a political one. Since justice is commonly taken to be a political virtue, these processes are assessed in terms of their procedural justice.

Section 3.3 turns from justice to value or goodness. A wide range of values are relevant to climate change, including non-human values such as biodiversity as well as human ones. Sections 3.3.3 to 3.3.6 concentrate on the value of human wellbeing. They consider how the wellbeing of different people is aggregated through a 'social welfare function' to determine 'social welfare', the overall value of a society.

From these more theoretical considerations about value, section 3.4 moves towards practical valuation as it appears in the methods of economics. It considers how practical valuations can be founded on a social welfare function. Section 3.4.3 considers an alternative, Paretian basis for valuations.

Section 3.5 takes up one aspect of valuation that is particularly crucial for climate change. How are costs and benefits that come in the – perhaps distant – future to be weighed against present costs and benefits? Future costs and benefits are normally discounted, and this section considers what is the appropriate discount rate to use.

3.3 Justice, equity and responsibility

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

In this section we review what the literature has to say regarding justice, equity and responsibility. We consider distributive justice, which is concerned with outcomes, and procedural justice, which is concerned with process. We also discuss compensation for damages and historic responsibility for harms. 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- and inter- as well as transgenerational justice.

An important caveat to this discussion is that there is no agreement in the literature on a 'correct' answer as to what is 'just'. We try to indicate where there are differences of opinion in the literature. As with everything in the IPCC, the review of the literature in this section is intended to be policy relevant but not policy prescriptive.

3.3.1 Causal and moral responsibility

People gain numerous benefits from engaging in greenhouse gas (GHG) emission-generating activities. In terms of the effects of GHG emissions, it makes no difference where on the globe the emissions occur. Much of the climate change that is caused by these emissions materializes several decades after the gas is emitted. Even though industrialization in the developed world is causally responsible for a large part of the build-up in greenhouse gases (Lamarque et al., 2010), people in the developing countries – in particular those living in the future – will suffer disproportionally more from climate change (IPCC, 2007 AR4, working group II, Summary for Policymakers) face an asymmetry: on the one hand, the highly industrialized countries have the main causal responsibility – in part owing to their past emissions – for climate change and potentially modest damages from future climate change. On the other hand, the developing countries have comparatively little historical and causal responsibility, may contribute the bulk of future emissions, but face potentially large risk of future damages from climate change.

This asymmetry suggests that we distinguish between the following questions of justice and moral responsibility: Do considerations of justice provide guidance in determining the appropriate (1) level of present emissions on a global scale, (2) distribution of emissions among those presently living, and (3) role of historical emissions in distributing global obligations? A further question is: who might be considered morally responsible for achieving justice, and thus could be considered a bearer of duties towards others? The question of moral responsibility is also of central importance in answering the question of who owes compensation for damages that are caused by emissions.

A separate issue is how decisions should be taken in the political realm. This is the subject of procedural justice (sec. 3.2.7).

3.3.2 Inter- and trans-generational justice and rights of future people

Intergenerational justice, or justice between generations, involves respect for the rights of and the fulfilment of duties to future and from past generations (Rawls, 1971) This reflects a broad understanding of justice, according to which justice considerations apply to intergenerational relations if future or past generations can be viewed as holding legitimate claims or rights against present generations, who in turn have corresponding duties to future or past generations. Intergenerational justice involves what currently living people owe to future people and what past people owed to us.[1]

One question of intergenerational justice concerns the duties of present generations towards future generations in view of the fact that present emissions affect the quality of life of future generations. Some justice theorists have offered the following argument for a cap on emissions (Caney, 2006a a; Meyer and Roser, 2009; Wolf, 2009): (1) future people's basic rights include rights to survival, health, and subsistence; (2) these basic rights are very likely to be violated when temperatures rise above a certain level; (3) currently living people can slow the rise in temperature by limiting their emissions, and they can do so at reasonable costs to themselves; thus, (4) a global cap on emissions is required for currently living people to fulfil their minimal duties of justice to future generations. In imposing a global cap, currently living people will help to ensure that future people will have a sufficiently good life (Rawls, 1999, p. 107, 2001, p. 159). What sort of life is sufficiently good is a matter of dispute among normative theorists (Page, 2007; Huseby, 2010). It is also a matter of dispute when an imposition of harm on future people is wrongful. For instance, it has been said that currently living people wrongfully harm future people if they cause future people to realize a much lower level of well-being than they enjoy themselves (Barry, 1999). (However, it is not clear that future generations will be worse-off than current generations, even with climate change. They may well be better-off, due to improvements in technology and investments in human capital.)

This line of reasoning is open to objection, since it presupposes both that present people can violate the rights of future people, and that the protection of future persons' rights is practically relevant for how present people ought to act.

[1] In the philosophical literature, "justice between generations" typically refers to the relations between people whose lifetimes do not overlap (Barry, 1977, pp. 243–244). In contrast, "justice between age groups" refers to the relations of people whose lifetimes do overlap (Laslett and Fishkin, 1992).

Some theorists claim that future people cannot hold rights against present people owing to special features of intergenerational relations, among them that mutual interaction between non-contemporaries is impossible, and that the number of future people who will exist, and their identity, is contingent upon the actions of present people. However, some justice theorists argue that the duty of justice not to violate other people's basic rights exists even if the bearer of the right cannot interact mutually with the bearer of the duty (Barry, 1989, p. 189; Buchanan, 2004 Part one). The contingency of future people's existence is relevant if future people could not be harmed (or benefited) by actions that are necessary for their existence. This is the so-called non-identity problem (Parfit, 1984 ch. 16; Heyd, 1992, p. 37,113). The non-identity problem arises if a person can be harmed by an action only if the action makes her worse off than she otherwise would have been. An alternative conception of harm evades the non-identity problem by claiming that people are harmed by any action that causes their quality of life to be below a certain threshold (McMahan, 1998, p. 223,229; Shiffrin, 1999; Harman, 2004; Shue, 2010)

3.3.3 Intragenerational justice: distributive justice

If an intergenerationally just global quota has been determined, and if there are going to be emission permits allocated under that quota, then the question of how emission permits ought to be distributed among the states (and, ultimately, the individuals) on this planet arises (Meyer and Roser, 2006; Caney, 2006a). By distributing tradable emission permits, we aim at a globally just distribution of benefits from emission-generating activities. Among the widely discussed views of distributive justice are strictly egalitarian views (Temkin, 1993) indirectly egalitarian views such as prioritarianism (Parfit, 1997), and sufficientarian views (Frankfurt, 1999). A strictly egalitarian position holds that equality is of intrinsic value, implying that we have a reason to worsen the state of better off persons for the sake of equality even though it is better for no one. Many find such levelling down objectionable (Holtug, 1998). According to prioritarianism, equality as such does not matter, but we ought to give some priority or greater weight to benefiting people who are not well off: If X is worse off than Y, we have at least a *prima facie* reason for prioritizing the promotion of the wellbeing of X over that of Y. Prioritarianism does not necessarily prescribe an equal distribution of goods, since some people may be able to draw more benefit from goods than others can. Prioritarianism has been criticized for not giving enough weight to improving the situation of the worst off people and for not distinguishing between the fulfilment of people's needs and the satisfaction of their mere wishes (Crisp, 2003; Benbaji, 2006). Sufficientarian views claim there is a level of wellbeing that all persons ought to have the opportunity of enjoying. Some commentators have objected that we cannot avoid an arbitrary specification of such thresholds (Arneson, 2000; Roemer, 2004). This section considers the implications of prioritarianism, the most common perspective on distributional justice.

We can distinguish two options for applying a principle of justice such as prioritarianism to the distribution of emission rights. Both of them are problematic. According to the first option, we ignore the distribution of other goods for pragmatic reasons when determining the fair distribution of emission rights. With the background distribution regarded as irrelevant, people can be considered neither worse off than others nor in a position to extract more benefits out of emission rights than others. Thus prioritarianism would demand a distribution of equal per capita emission rights. According to the second option, we distribute emission rights in light of the currently highly unequal distribution of other assets. If we assume tradability of emission rights in an effective and fair global market, the scope for unequal benefiting from emissions is reduced (depending on how they are initially distributed), because those who would benefit little from emission rights can sell them. However, it is possible that people in the developing world are so much less well off than the developed world that we could give many more, and possibly all, emission rights to them, and they might still be worse off than many people in the industrialized countries. However, it is questionable to aim at bringing the overall distribution of goods closer to the prioritarian ideal by adjusting the distribution of only one particular good (Caney, 2006a).

3.3.4 Historical responsibility and distributive justice

Historical responsibility with respect to climate change concerns the past contributions made by various countries to the stock of greenhouse gases in the atmosphere. The Framework Convention on Climate Change (UNFCCC) refers to "common but differentiated responsibilities" among countries of the world. This is usually interpreted to imply that current and historic differences among countries should play a role in determining emission reduction obligations (Rajamani, 2000).[2]

Some ethical theorists have argued that the distribution of emission rights (given that they are to be limited) and other burdens and benefits among the present generation must take into account the differing levels of past emissions and their effects on the wellbeing of currently living and future people (see, e.g.,Gosseries, 2004; Meyer and Roser, 2006; Caney, 2006b; Posner and Weisbach, 2010 ch. 5). A number of objections have been raised against taking into account past emissions (see, e.g.,Gosseries, 2004; Caney, 2005; Meyer and Roser, 2006; Posner and Weisbach, 2010 ch. 5). First, as currently living people cannot possibly influence what previously living non-contemporaries did, they cannot be held causally responsible for the actions of their ancestors. Second, previously living people could not reasonably have been expected to know of, the harmful consequences of their emissions on (more remote) future people; thus they can be excused by ignorance of the consequences of their actions. Third, and owing to the non-identity problem (section 3.2.3), people living today would not exist at today's level of prosperity had previously living people not engaged in the emission-generating activities as they did, and thus nobody is better or worse off owing to the emissions of previously living people.

From the perspective of distributive justice, these objections do not speak against taking into account past emissions and their consequences. If we are only concerned with the distribution of benefits from emission-generating activities during the lifespans of individual persons, then we could take into account present persons' benefits from their own emission-generating activities since their birth. Also, present people have benefited since birth or conception from past people's actions that have emissions as a side-product. These two ways of taking into account the consequences of (some of the) past emissions are not open to the first and the second objection as described in the previous paragraph. Also, the non-identity problem, on which the third objection is based, is not relevant as the two ways of taking past emissions into account concern the distributive effects of emission-generating activities only after the identities of people have been determined, namely since their conception. Thus, if in distributing emission rights we aim at distributing benefits from emission-generating activities, then according to prioritarian standards those who have inherited a disproportionally large share of benefits from their predecessors – e.g., a well-functioning infrastructure and tertiary education system established before those presently alive were born – should receive a smaller share of emission rights relative to some unspecified baseline.

Associated with the historical responsibility concept are related concepts, including historical inequity (Agarwal and Narain, 1991) equal rights to environmental space (Simms, 2001), ecological footprints, the polluter pays principle, and ecological debt (Jernelöv, 1992; Hayes and Smith, 1993; Azar and Holmberg, 1995). These concepts and some of the literature on historical responsibility in the UNFCCC are reviewed by Friman (2007).

[2] Additionally, under the UNFCCC Articles 4.3 and 4.5, developed countries committed to provide financial resources and to transfer technology to support developing countries in taking their climate-related actions; while Article 4.7 links the extent to which developing countries meet their Convention commitments to the implementation of the finance and technology commitments of developed countries (United Nations, 1992)

3.3.5 Intra-generational justice: compensatory justice and historical responsibility

A further basic issue is whether those who suffer disproportionally from the consequences of climate change have just claims to compensatory measures against those who are the main causers or beneficiaries of climate change (see, e.g.,Neumayer, 2000; Gosseries, 2004; Caney, 2006b b). One way to distinguish compensatory from distributive claims is to rely on the idea of a just baseline distribution that is determined by a criterion of distributive justice and by changes in the distribution, which someone realizes as a result of his own responsible choices. Deviations from this baseline owing to wrongful actions call for compensatory measures; other deviations (e.g., owing to luck or other non-wrongful actions) call for re-distributive measures in the sense of a levelling out of undeserved benefits or harms. Under this approach, compensatory duties to pay for climate damages and adaptation costs would have to rely on the wrongfulness of what was done. Defining "wrongful" is a matter of normative theory and not easy.

We can distinguish three versions of compensatory payments depending on who has the duty to make payment (Gosseries, 2004; Caney, 2006b b): the emitter of wrongful emissions, or the beneficiary of wrongful emissions, or some individuals due to their membership in a community of which (they or) some other (previous) members caused the wrongful emissions. Accordingly we can distinguish three principles of compensatory justice: the Polluter Pays Principle (PPP), the Beneficiary Pays Principle (BPP), and the Community Pays Principle (CPP).

According to the Polluter Pays Principle (PPP), the duty bearer for compensatory payments is the emitter of emissions. In this context, someone emits wrongfully if (1) he or she exceeded his or her fair share (determined along the lines as outlined in sections 3.2.2), and (2) he or she knew or was liable to know about the harmfulness of his emissions. Someone is wrongfully harmed by emissions if he or she either (1) is worse off due to wrongful emissions than he or she would otherwise be, or (2) falls below a specified threshold of harm due to wrongful emissions, or both. The PPP is widely discussed but is far from universally accepted. As a general principle of compensatory justice – disregarding whether it can be usefully applied in climate change context – the principle that the emitter of wrongful emissions has the duty to provide compensatory payments (PPP) is more widely accepted than both BPP and CPP.

There are at least four basic problems for justifying compensatory payments in the context of climate damages. These have implications for what duties of compensation and what rights to receive compensation can and cannot be justified for currently living people. The first two problems were already introduced in section 3.2.4 on historical responsibility and distributive justice:

First, potential duty bearers might have been (blamelessly) ignorant. It is unclear at what point people could have been reasonably expected to have knowledge of the harmful effect of greenhouse gas emissions (Gosseries, 2004, pp. 360–361). Thus, for all or for some period of their lives, previously as well as currently living people might have been (blamelessly) ignorant of the harmful consequences of their emissions on future people.

Second, due to the non-identity problem (see section 3.2.3), potential recipients might only be said to be harmed according to a threshold conception of harm. Thus, currently living people can only claim to be wrongfully harmed if they fall below the threshold of wellbeing owing to the consequences of historical emissions. They cannot be said to be harmed simply because climate quality is worse than it would be had there been less emissions in the past. However, as has been argued in section 3.2.3 , there is no agreement on how best to specify the relevant thresholds for wellbeing.

Third, again due to the non-identity problem, potential payers might not be said to have benefited. Without past emissions, they would not be worse off but rather not exist at all.

Fourth, potential duty bearers might be dead, and thus cannot have a duty to provide measures of compensation.

The Polluter Pays Principle therefore has difficulties in ascribing compensatory duties and in identifying wronged persons. Owing to the first and fourth problems just mentioned, the principle will be able to ascribe duties of compensation only to currently living people for their more recent emissions, even though there are many more people causally responsible for current and future harmful effects of climate change. With respect to the damages caused by past emissions, compensation payments are only justifiable for a small part of the problem.

The Beneficiary Pays Principle (BPP) might be justified on the basis of there being weightier reason to even out undeserved deviations from a just baseline that are due to a wrong than to even out deviations that are due to more general causes. Some currently living people can be seen as currently benefiting from past emissions that impose costs on other currently living people. Accepting benefits from wrongful emissions can possibly be seen as transferring (some of) the wrongdoer's duty of compensation to the beneficiary (Gosseries, 2004). Also condemnation of injustice can be thought to imply not being willing to benefit from it while others suffer from it (Butt, 2007, p. 143). However, BPP is open to at least two objections. Owing to the non-identity problem, currently living people can only be said to have benefited since birth or conception from the emissions of past people (see section 3.2.4). Their duties of compensation based on BPP only concern past emissions that have had beneficial consequences for them; all other past emissions remain uncovered. Second, if voluntary acceptance of benefits is a condition of their giving rise to compensatory duties, the potential bearers of the duties must be able to feasibly forego the benefits in question. Otherwise the acceptance cannot be considered voluntary.

The Community Pays Principle claims that members of a community – and many countries will count as such – can have collective outcome or remedial responsibility (Miller, 2004, pp. 244–247; Meyer, 2005, pp. 228–249) for wrongful actions of other members of the community, including past members. Due to their membership in the transgenerational community, currently living members can have a duty to shoulder the burdens, which go along with the wrongful actions of past members without being in any way morally or causally responsible for these actions. It is a matter of debate whether and, if so, under what conditions currently living people can be said to have inherited compensatory duties. While reliance on CPP solves the fourth of the problems listed (that is, potential polluters might be dead), compensatory payments along the lines of CPP still only cover wrongful emissions that can be shown to be harmful. Thus, emissions made under ignorance of their harmful nature remain uncovered.

These findings of the limited applicability of principles of compensatory justice can be qualified in at least two ways. First, given that many effects of climate change can be seen as undeserved harms – and harms that go along with undeserved benefits for other persons – levelling off such effects on the basis of a concern for distributive justice is an equally plausible response. Principles of distributive justice can also be applied (at least to some degree) to the distribution of duties to pay for adaptation measures to those who suffer from climate damages. It has been suggested that these duties should be allocated mainly to the highly industrialized and rich countries according to their ability-to-pay that reflects their causal role in bringing about the problem in question (Shue, 1999; Caney, 2010; Gardiner, 2011). Secondly, currently living people stand under intergenerational duties of justice with respect to climate justice if they can be said to know not only about the seriously harmful consequences of their emission-generating activities for future people, but also about effective measures that they can implement at reasonable costs to themselves to protect future people's basic rights (see, e.g.,Birnbacher, 2009; Gardiner, 2011). Failing to fulfil their duties vis-à-vis future people would then constitute harmful wrongdoing.

3.3.6 Legal concepts of historical responsibility

Legal concepts are relevant as reflections of how societies have actually dealt with problems of responsibility for environmental harms initially thought to be benign. Legal systems have long struggled to define the boundaries of responsibility for harmful actions and are now beginning to do so regarding climate change. It remains unclear whether courts will accept lawsuits against greenhouse gas emitters as a basis for liability and legal scholars vigorously debate whether liability exists under existing law (Mank, 2007; Faure and Peeters, 2011; Haritz, 2011; Kosolapova, 2011; Kysar, 2011; Gerrard and Wannier, 2012).

The two primary legal systems in the world, common law and civil law, differ, but both would require inquiry into whether emission of greenhouse gases falls into a defined category of tortious conduct (Hunter and Salzman, 2007; Faure and Peeters, 2011; Brunée et al., 2012). If some or all past emissions satisfy that standard, the next issue in both common law and civil law countries would be the nature of the causal link with the resulting harm (Faure and Peeters, 2011; Haritz, 2011; Brunée et al., 2012).

Across legal systems, harmful conduct is generally a basis for liability only if it breaches some legal norm (Tunc, 1983) such as negligence, or an unreasonable interference with the rights of the public or of property owners (Mank, 2007; Kysar, 2011; Brunée et al., 2012; Goldberg and Lord, 2012; Koch et al., 2012). Negligence is based on the standard of the reasonable person or the *bone pére de famille* (Wagner, 2007). Similarly, nuisance liability does not exist if the actor did not know or have reason to know the effects of its conduct (Antolini and Rechtschaffen, 2008). With regard to liability for environmental damage, the European Union but not the United States recognizes a similar exemption from liability (United States Congress, 1980; European Union, 2004). Similarly, in European law, a defendant is not responsible if the state of scientific knowledge at the time did not enable the discovery of a product defect (European Commission, 1985). In the United States, many states recognize a similar limitation in cases involving defective product design (Dana, 2009). For greenhouse gases, some legal scholars suggest that culpability arose after the express international determination of the harmfulness of such emissions in 1990, but others argue in favor of earlier dates (Faure and Nollkaemper, 2007; Hunter and Salzman, 2007; Haritz, 2011). Presumably, some may suggest a later date.

Legal systems also require a suitable causal link connecting a defendant's conduct and some identified harm to the plaintiff (Tunc, 1983; Kosolapova, 2011; Brunée et al., 2012). Plaintiffs would need attribution evidence to connect a specific harmful event to climate (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 also some degree of causal foreseeability or directness (Mank, 2007; Kosolapova, 2011; van Dijk, 2011; Ewing and Kysar, 2012). Under both civil law and common law, emitters could argue that their contribution to GHG levels was too small and the harmful effects too indirect and diffuse to satisfy requirements of proximate cause or legal cause (Faure and Peeters, 2011; Kysar, 2011; van Dijk, 2011; Gerrard and Wannier, 2012).

Climate change claims might also be based on a theory of unjust enrichment, which does not necessarily require a tort (Kull, 1995; Birks, 2005). But legal systems do not attempt to remedy all forms of enrichment that might be considered unjust from an ethical perspective (Zimmermann, 1995; American Law Institute, 2011; Laycock, 2012). In various legal systems, liability turns on whether benefits have been conferred without legal obligation or through a transaction that is insufficient to work a conclusive alteration in ownership (Zimmermann, 1995; American Law Institute, 2011; Laycock, 2012). Application of these principles to climate change is unclear.

As the preceding discussion has indicated, legal systems do not recognize liability whenever a positive or negative externality exists, but instead engage in line-drawing based on the type of conduct creating the externality and the nature of the causal connection between an actor's conduct and the resulting gain or loss to another.

3.3.7 Procedural justice

Procedural justice requires that public decisions be taken in a fair way, independent of outcome. The core idea is that relevant actors are included or represented in the political process and that they have a fair say in the decision (Albin, 2001; Caney, 2005). Procedural justice is to be contrasted with distributive justice, which is concerned with the distribution of benefits and burdens in the outcome of a decision (Paavola et al., 2006; Paavola and Adger, 2006; Walker, 2012, p. 10).

3.3.7.1 The nature of procedural justice

Accounts of procedural justice have at least three components.

The first concerns the types of agents who should be included. At the international level, it is assumed that the primary actors to be included are representatives of states. Some argue that representatives of civil society (such as members of NGOs or social movements) also have some right to be included. Others argue that different normative perspectives must be represented in the process (Caney, 2005; Dryzek, 2010; Stevenson and Dryzek, 2012a; b).

Second, accounts of procedural justice must specify and justify the normative principle that determines which particular actors are entitled to be included in a political process. One common view appeals to what has been termed the "all-affected principle" (Whelan, 1983) , which holds that all of those who are affected by a political process should be included in the process. More recent versions of this principle hold only that those whose vital interests are profoundly and involuntarily affected by a political processes should be included in it (Goodin, 2003; Held, 2004; Caney, 2005; Pogge, 2008). An alternative to the "all-affected" principle maintains that those who are legally bound by the decisions of a political body should be included in the body's processes (Karlsson, 2008).

A third component concerns the nature of the rights to which participants are entitled. One perspective is that procedural justice requires simply that those affected are *informed* about the issues under consideration. A more substantive version of procedural justice holds that it requires more than information: all who are affected should be *consulted*. A third version holds that those affected are entitled to *participate* in the political process or at least to be *represented*. Procedural justice is thus associated with democratic decision-making, and in particular with an ideal of 'deliberative democracy' (Dryzek, 2010).

3.3.7.2 Contexts for procedural justice

Levels*.* Procedural justice can apply at different levels of governance, and the form it should take will vary with the context. Some have emphasized the importance of ensuring that international negotiations on climate change should take a multilateral form and include all affected agents. Some have argued that international negotiations should seek to embody democratic principles and are sympathetic to the vision of a 'cosmopolitan democracy' (Bäckstrand, 2011; Held and Hervey, 2011). The precise form that procedural justice will take at these different levels, and the extent to which it can realize democratic ideals, will depend, in part, on what is feasible.

Scope. Since climate change is a global problem, some have argued that procedural justice requires international climate negotiations to be maximally inclusive (Bäckstrand, 2011; Held and Hervey, 2011). Since climate change is also an intertemporal problem, some have proposed reforming existing political institutions and practices to make them more forward-looking, and to induce them to take into account the interests of future generations (Dobson, 1996; Goodin, 2003; O'Neill, 2007).

3.3.7.3 Justification

Procedural justice is valued for a number of distinct reasons. First, some hold it is the only way to make political decisions legitimate (Paavola et al., 2006; Paavola and Adger, 2006) because unless affected parties are included in the decision process they are not treated with respect (Schlosberg, 2007).

Second, it is argued that procedural justice increases compliance with the decisions made and thus contributes to the effectiveness of the policies selected.

A third view holds that just procedures are more likely than others to produce outcomes that are just according to some independent criterion. This makes them a case of what Rawls terms "imperfect procedural justice" (Rawls, 1971 section 14).

3.4 Values and wellbeing

The outcomes of a decision may be evaluated against various criteria or values. Any decision is likely to promote some values and damage others. To assess it properly, each of these values must be taken into account.

The relative importance of different values will vary with the circumstances. For example, in a developing country, special priority may need to be given to improving people's material conditions such as their access to health care, whereas richer countries may have the freedom to devote more resources to environmental improvements.

The overall value of an outcome is determined by the aggregate of all the particular values it promotes or damages. Different values must therefore be weighed or balanced against each other. But some pairs of values differ so radically that they cannot be determinately weighed together. For instance, 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 the value of biodiversity against human wellbeing. When values cannot be determinately weighed, they are said to be 'incommensurable' (Chang, 1997). When a decision involves incommensurable values, arguably it may turn out that none of the options is determinately the best. In such a case, only the merits of the decision-making *process* (which were examined in section 3.2.7) can determine whether a decision is right.

Values may be classified into non-human and human values.

3.4.1 Non-human values

Nature provides great benefits to human beings, in ways that range from processing our waste to beautifying our surroundings, as well as in more intangible ways. Nature has intrinsic value to many people, over and above its instrumental value. It is often argued that nature also has value in its own right, besides its value to humanity.

Some philosophers claim that rational adult humans have a kind of unconditional moral worth – sometimes called "dignity" – that is not found elsewhere on earth (Kant, 1956). Other philosophers believe that worth can be found elsewhere (Dryzek, 1997). They typically start by noting that many human beings themselves lack rationality or subjectivity, yet still have worth. The very young and the very old, not to mention people with various kinds of physical and mental impairment, are among them. Why, then, deny worth to those animals that have a subjectivity and show emotional sophistication in their lives (Regan, 2004), and who are vehicles for pleasure, pain, suffering, joy and other experiences (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 living on earth sets out to destroy every living thing, animal or plant. Most people believe his actions 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). Some philosophers argue that there is value in the lives of all organisms, to the extent that they have the capacity to flourish or to languish (Taylor, 1986; Caney, 2005).

Other philosophers have argued that biological communities and holistic ecological entities also have value in their own right. Some have argued that there is more value in a species than in all of its individuals together, and still more value in an ecosystem (Rolston, 1988, 1999; compare discussion in ; Brennan and Lo, 2010 ch. 5)

If these claims about the value of nature are right, climate change may lead to a rapid, large-scale destruction of value.). The loss of environmental diversity, the extinction of plant and animal species, and the suffering of animal populations are possible consequences of climate change.

The human value of these harms is hard to measure; the non-human value is much more difficult if not impossible to measure. Non-human values cannot be measured by economic techniques, which pertain to human values (see Section 3.4). People are willing to pay for preserving features of nature even if they expect no benefit to themselves from them (Aldred, 1994). But when a good is not a benefit to people, there is no reason to think that an aggregate of people's willingnesses to pay for it is a measure of its value (Broome, 2009).

3.4.2 Cultural and social values

Human values divide into those that contribute to the good of a community as a whole and those that contribute to the good of humans as individuals. The former include cultural and social values; the latter constitute human wellbeing (we understand a person's wellbeing in this broad sense that includes anything that is good for a person.)

Climate change threatens damage to cultural artefacts and to cultures themselves. For example, some have claimed that damage is already being done to the culture of Arctic indigenous people (Ford et al., 2008). Cultural values and indigenous people are discussed in section 3.10.2

The degree of equality in a society is sometimes taken to be an example of a social value. 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 accounted for, not as a separate social value, but within the aggregation of individual people's wellbeing.

3.4.3 Wellbeing and its aggregation

Human wellbeing is one important value that needs to be taken into account in decision-making. What constitutes a person's wellbeing? This question has been the subject of an extensive literature since ancient times.[3] 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 that it consists in a number of the ordinary goods things of life, such as health, wealth, a long life, participating well in a good community, and so on. The 'capabilities approach' in economics (Sen, 1985) 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. The Human Development Index is intended to be an approximate measure of wellbeing understood this way (UNDP, 1990).

[3] For example: Aristotle, *Nicomachean Ethics*. Recent work includes: (Griffin, 1986; Sumner, 1996; Kraut, 2007)

We do not try to assess these differing views about the nature of wellbeing. Here we concentrate on the *aggregation* of wellbeing: how does the wellbeing – whatever it is – of different individuals together determine the value or goodness of a society as a whole?

Assume that each person has a level of wellbeing at each time she is alive, and call this her *temporal wellbeing* at that time. Taking a society together, temporal wellbeing is distributed across times and across the people in the population. When a choice is to be made, each of the options leads to a particular distribution of temporal wellbeing. A stylized choice between two options is shown in Figure 3.1.

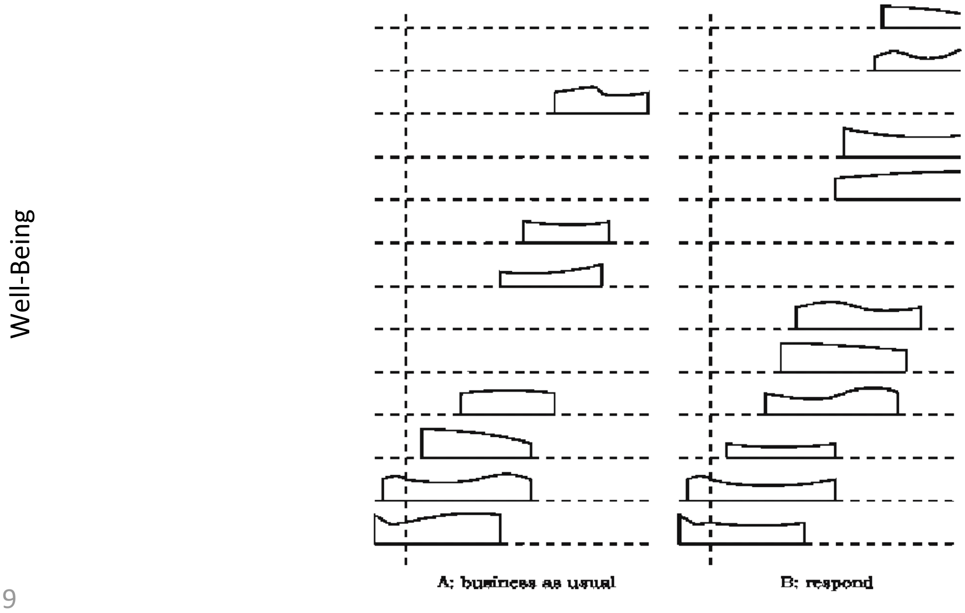

Figure 3.1. Comparing two distributions of wellbeing: The diagram illustrates in stylized fashion the choice between business as usual and responding to climate change. Each half of the diagram shows the distribution that will result from one of these options. Time is measured horizontally. Each horizontal pair of dotted lines displays the life and wellbeing of one particular person. If the person lives at all in either option, the little graph on her line shows the time when her life begins and when it ends, and the height of the graph shows her temporal wellbeing at each time she is alive. If the person will not live at all in one of the options, there is no graph on her line for that option. A vertical line in each half of the diagram marks the present. The distributions are arbitrarily drawn for the purpose of illustrating some typical features of decisions about climate change.

The diagram makes the implicit assumption that each person's temporal wellbeing, at every time she is alive, is measurable by a number. It assumes the measurement is on a ratio scale (a cardinal scale in which significance is attached to the zero of wellbeing), which is intertemporally comparable. Accounts of measuring wellbeing are available (e.g., see Drèze and Stern, 1987; Broome, 2004, pp. 78–103; Oswald and Wu, 2010)

We need to assess the value of distributions of wellbeing like this. This involves aggregating temporal wellbeings across each distribution to arrive at an overall, social value for the distribution. The diagram illustrates some of the special problems of aggregation that are raised by climate change. In the option *respond,* people living in the further future have greater temporal wellbeing and live longer lives than they do in *business as usual*, but *respond* requires some sacrifices of temporal wellbeing in the near future. Another feature is that the choice between the options affects the population of people who live in the future.

3.4.4 Lifetime wellbeing functions

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. Technically, this is the assumption that each person's wellbeing is *separable*. It allows us to split aggregation into two steps. First, we aggregate each person's temporal wellbeings across the times in her life to determine her lifetime wellbeing. For this we need to specify *lifetime wellbeing functions*, which express each person's lifetime wellbeing as a function of her temporal wellbeings. Second, we aggregate lifetime wellbeings across people to determine the social value of the distribution. For this we need to specify a social value function – often known as a *social welfare function* – which expresses the social value of a distribution as a function of the people's lifetime wellbeings.

It seems reasonable to assume that each person's lifetime wellbeing function has the same form. This form is not much constrained by theory, and in the literature it has generally been left to intuition. Many different forms have been proposed.

The most straightforward makes a person's lifetime wellbeing 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. They take a person's lifetime wellbeing to be the total number of years she lives, adjusted for her health in each year.[4] Since wellbeing actually does not depend on health only, qalys or dalys provide at best only a rough approximation to a lifetime wellbeing function. If they are aggregated across people by simple addition, this is to assume implicitly that a year of healthy life is equally as valuable to one person as it is to every other. This 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; but see also Currie et al., 2008)

Other authors take lifetime wellbeing to depend on the 'shape' of a life. It is sometimes said that, for a given total of temporal wellbeing, a life that improves over time is better than one that declines (Velleman, 1991). This view is supported by the idea of consumption habit formation (see for example Campbell and Cochrane (1999). An opposite view discounts later times, which means that, for a given total of temporal wellbeing, a life that declines over time is better than one that improves (Fuchs and Zeckhauser, 1987).

3.4.5 Social Welfare Functions

Some economists have claimed that interpersonal comparisons of wellbeing are impossible.[5] If that is so, the wellbeings of different people are incommensurable and cannot be aggregated. This sceptical view leads to the Paretian approach to valuation, which is considered in section 3.4.3 .

In this section we set it aside, and assume that temporal wellbeings are measured in a way that is comparable across people.[6] This allows us to proceed to the second step of aggregation, which is to aggregate different people's lifetime wellbeings through a social welfare function, to arrive at social value or 'social welfare'.

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[4] For qalys, see Sessi (2006, pp. 402–408) for dalys, Murray(1994).

[5] Examples are: Robbins (1937) Archibald (1959)Arrow (1963, p. 9). A survey and discussion of this sceptical view appears in Hammond (1993).

[6] Potential bases of interpersonal comparisons are examined in: Fleurbaey and Hammond, (2004); Sen,(1982, pp. 264–281); Elster and Roemer,(1993); Broome, (2004 section 5.3); Arrow, (1977).

We shall first consider social welfare functions under the simplifying but unrealistic assumption of a constant population. We assume 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 grounds for thinking that, for constant population, the social welfare function is *additively separable* between people. This means it has the form:

Equation 3.1. $V = v_1(w_1) + v_2(w_2) + \ldots + v_J(w_J)$.

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 assumes that the social welfare function is defined, not just on distributions of wellbeing like the ones illustrated in Figure 3.1, but on uncertain prospects of these distributions. It assumes that the function satisfies the axioms of expected utility theory (see Chapter 2). It also assumes that it is Paretian: if one prospect is better for someone than another, and worse for no one, then it is has greater social welfare. These assumptions are plausible, but they can be challenged (Diamond, 1967; Broome, 2004 ch. 6-11; Fleurbaey, 2010). So, although the additively separable form is commonly assumed in cost-benefit analysis, 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 section 3.2.2 and is defined below. The value of inequality cannot be given 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. 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 section 3.5

Within this additively separable form, different ethical theories imply different social welfare functions. *Utilitarianism* values only the total of people's wellbeing. Its social welfare function is

Equation 3.2. $V = w_1 + w_2 + \ldots + w_J$

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 the people.

Prioritarianism has the social welfare function

Equation 3.3. $V = v(w_1) + v(w_2) + \ldots + v(w_J)$

where the function $v()$ is *increasing* and *concave*. This means that the graph of $v()$ has an upward slope but a downward curvature. (Section 3.4.2 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.) A prioritarian function values each person's wellbeing in the same way. However, improving a person's wellbeing contributes more to social welfare if the person is badly off than if she is well off. The slogan of prioritarianism is 'priority to the worse off'. It indirectly gives value to equality in the distribution of wellbeing: it implies that a given total of wellbeing is more valuable the more equally it is distributed (Sen, 1973; Weirich, 1983; Parfit, 1997).

A *maximin* social welfare function, which was inspired by the writing of Rawls (1971), takes the value of a distribution to be given simply by the wellbeing of the worst-off person (for example Phelps,(1973); Boadway & Jacquet, (2008); Hammond, (1976)). This is an extreme sort of prioritarianism. But the maximin social welfare function is not additively separable, so it is not consistent with Harsanyi's theorem.

3.4.6 Valuing population

Next we evaluate distributions that do not necessarily have the same population. Climate change can be expected to have a major effect on the world's human population. There is a small chance that severe climate change will lead to a catastrophic collapse of the population (Weitzman, 2009), and even to the extinction of human beings. Valuations of the impact of climate change and of policies to mitigate climate change therefore need to take changes in population into account.

The utilitarian and prioritarian social welfare functions 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 social welfare function is the average of people's wellbeing. Policy-making often aims to promote per capita wellbeing, which is to adopt average utilitarianism (Hardin, 1968). This goal tends to favour anti-natalist policies, aimed at limiting population.

The utilitarian function may alternatively be extended to *total utilitarianism*, whose social welfare function is the total of people's wellbeing (Sidgwick, 1907, pp. 414–416). It may also be extended to *critical-level utilitarianism*, whose social welfare function is the total of the amount by which each person's wellbeing exceeds some fixed critical level. It is

Equation 3.4. $$V = (w_1 - c) + (w_2 - c) + \ldots + (w_J - c)$$

where c is the critical level (Broome, 2004; Blackorby et al., 2005 ch. 10).

Total utilitarianism is critical-level utilitarianism with the critical level set to zero. Its meaning is indeterminate until it is settled which level of lifetime wellbeing is counted as zero. The zero is sometimes set at the level of a life that has no good or bad experiences – that is lived in a coma throughout, for instance (Arrhenius, 2011 section 2.2.3 and 2.2.4). Since people on average lead better lives than this, total utilitarianism tends to be less anti-natalist than average utilitarianism. However, it does not necessarily favour increasing population. Each new person damages the wellbeing of many existing people, through her emissions of greenhouse gas and the demands she makes on Earth's other limited resources. This counts against creating new people, according to total utilitarianism.

Each of the existing ethical theories about the value of population has intuitively unattractive implications (Parfit, 1986 part 4). Average utilitarianism is subject to particularly severe objections. Arrhenius (2011) crystallizes the problems of population ethics in the form of impossibility theorems. So far no consensus has emerged about the value of population.

3.5 Aggregation of costs and benefits

Practical valuation in economics – which is required in cost-benefit analysis, intertemporal optimization using integrated assessment models (e.g.,Stern, 2007; Nordhaus, 2008) and other applications – may be founded on the idea of a social welfare function, which was introduced in section 3.3. This basis of valuation is considered in sections 3.4.1 and 3.4.2. An alternative, Paretian, basis is considered in section 3.4.3.

3.5.1 Aggregation at a time

If practical valuation is to be based on a social welfare function, some strong assumptions must be made about the form of the function. Most often in practice, a distribution of wellbeing is aggregated in two steps. First temporal wellbeing is aggregated across people at each time, to determine a social value for each time. Then these values are aggregated across times.[7] This implies

[7] An exception is Murphy and Topel, (2006)

that times are separable in the social welfare function. Combined with the assumption made in section 3.3 that each person's wellbeing is weakly separable, it has the very strong consequence that the social welfare function is additively separable throughout (Gorman, 1968). Granted an appropriate assumption of symmetry between different people and times, it leads to the social welfare function:

Equation 3.5. $$V = \delta^1[v(w_1^1) + v(w_2^1) + \ldots + v(w_I^1)] + \delta^2 [v(w_1^2) + v(w_2^2) + \ldots + v(w_I^2)] + \ldots + \delta^T[v(w_1^T) + v(w_2^T) + \ldots + v(w_I^T)]$$

where w_i^t is the temporal wellbeing of person *i* at time *t*. Each bracket shows social value at a particular time *t*. The function *v*() shows the value of temporal wellbeing: how much a person's temporal wellbeing at a time contributes to social value at that time. δ^t is a *pure* discount factor, which discounts social value at the time *t*.

This formula for value has unsatisfactory consequences. If the function *v()* is strictly concave, it expresses prioritarianism for temporal wellbeings, which gives an indirect value to equality among people at each time. But the formula cannot give value to lifetime equality. If, say, everyone's lifetime wellbeing is the same, but each person's temporal wellbeing increases during her life, this formula will account the society as unequal. Moreover, it is inconsistent with average utilitarianism, or with valuing per capita temporal wellbeing at any time, whereas per capita wellbeing is a common object of policy. These consequences arise from the assumption that times are separable in the social welfare function. But this assumption is hard to avoid in practical evaluation.

Practical decision-making requires some alternative policies or actions to be assessed as better or worse than others; it therefore needs an assessment of differences in value rather than absolute values. We may treat one of the alternatives as a standard of comparison – for instance, the status quo or business as usual – and assess the value of other alternatives relative to this standard. Relative to the standard, each option will have costs and benefits. Their values need to be measured and aggregated together. Costs and benefits are such things as an increase or decrease in the consumptions of particular commodities by the particular individuals, external harms such as pollution and damage to health caused by climate change, public goods and bads such as environmental damage, and so on.

3.5.2 Monetary values and cost-benefit analysis

The first step in a practical economic valuation is to assign a *monetary value* to the non-monetary costs and benefits that come to each person at each time. Whether a change is a cost or a benefit, two different monetary values can be assigned to it: the equivalent variation and the compensating variation. The equivalent variation is the amount of money that would have the same effect on the person's temporal wellbeing as the change itself. The *compensating variation* is the amount of money that would compensate the person for the change. For a benefit, the compensating variation is the person's *willingness to pay* for the change; for a cost, it is her willingness to accept compensation for it. If a change is marginal, the compensating and equivalent variations will be equal. If a marginal change is an increase or decrease in the person's consumption of a marketed commodity, consumer theory shows its equivalent and marginal variations will both be equal to the price of the commodity.

Monetary values may be estimated by various methods. If markets are efficient and undistorted, the monetary value of marketed commodities is given by their market prices. For non-marketed goods, surrogates can sometimes be found among market prices. For example, a monetary value can be attached to life saving on the basis of the wage premium that is paid for dangerous jobs that expose people to a risk of death (Thaler and Rosen, 1976). Alternatively, valuations can be based on surveys that ask people what they would be willing to pay for a benefit or be willing to accept as compensation for a loss. These are *contingent valuation methods*. They are subject to controversy (Arrow et al., 1993; Hanemann, 1994).

For a marginal change, the monetary value of a change for a person is the amount of money that would have the same effect on the person's wellbeing as the change itself. So once the monetary value is established, the effect of the change on the person's wellbeing can be derived. It is the monetary value multiplied by the rate at which money contributes to her wellbeing. This latter is the *marginal utility of money* to the person. ('Utility' in this context to refers to wellbeing.) The marginal utility of money is an empirical feature of the person. It is commonly assumed to diminish with increasing income (Marshall, 1890; Dalton, 1920; Pigou, 1932, p. 89; Atkinson, 1970). That is to say, a person's wellbeing is generally taken to be a strictly concave function of her income or of her aggregate consumption.

The effects of the change of each person's wellbeing at each time must next be aggregated across people to determine the effect on social value at that time. Equation 3.5 shows what is required. Social value is the sum of the values of each person's wellbeing. Each person's wellbeing contributes to social value through the value function $v()$. The change in wellbeing must therefore be multiplied by the *marginal value of wellbeing*, or the *marginal value of utility*, which is the first derivative of this function. The marginal value of wellbeing is an ethical parameter. According to utilitarianism, it is constant and the same for everyone. According to prioritarianism, it diminishes with increasing wellbeing.

In sum, the effect of a change on social value at a time is found by taking the monetary value of the change to each person, weighted appropriately, and adding up these weighted amounts. The weights – often called 'distributional weights' – are the marginal utility of money multiplied by the marginal value of utility: an empirical factor multiplied by an ethical factor. Both utilitarianism and prioritarianism imply that the better off a person is, the lower the weight that should be attached to her monetary values.

Much practical cost-benefit analysis values costs and benefits according to monetary values, added up without any weighting factor. This is implicitly to assume that the weighting factor is the same for each person. It is a particularly egregious error in cost-benefit analysis concerned with climate change, which often needs to take into account the extremes of wealth between rich and poor countries. An important example was described in the Second Assessment Report of the IPCC (1995, pp. 196–197), where it considered the value of human life. 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. However, even within a developing country, weighting can make a difference. Drèze (1998) examines reducing pollution in Delhi (India) and contrasts the relatively rich New Delhi with the poorer Old Delhi. If the criterion is reducing pollution for the greatest number of people the focus will be on projects in Old Delhi; on the basis of unweighted net benefits, the focus will be on New Delhi.

Box 3.1. Value of life

Climate change may shorten many people's lives, and mitigating climate change may save many people's lives. Lives must therefore be included in any cost-benefit analysis that is concerned with climate change. CBA needs to set a quantitative value on the harm done a person when her life is shortened, or, equivalently, on the good done her when her life is extended.

This task has been approached in the literature from two different directions. One approach is based on the length of the period of life that the person gains or loses, adjusted for the quality of her life during that period. This gives a measure of the value of life known as the 'quality-adjusted life year' or qaly (Sassi, 2006, pp. 402–408). Qalys are widely used to value lives in health economics and in public health. The World Health Organization uses the 'disability-adjusted life years' or daly, which is similar (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. Willingness to pay measures of the value of life are widely used in environmental economics (E.g. U.S. Environmental Protection Agency, 2010 Appendix B)

The main differences between these approaches are:

1. Since willingness to pay is measured in money, it is immediately comparable with other values measured in money. Qalys need to be assigned a money 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 willingness to pay methods generally leave it entirely to the individual to set a value on extending her own life (Broome, 1994).

3. Implicit in each measure is a different basis for interpersonal comparisons of value. When qalys are additively aggregated across people, the implicit assumption is that a year of healthy life has the same value for each person. When willingness to pay is aggregated across people by addition (without distributional weights), that is implicitly to assume 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 is more plausible.

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 willingnesses to pay for extending life. If appropriate weights are applied, willingness to pay becomes more nearly proportional to qalys. Indeed, if we adopt the assumption that a qaly has the same value for each person, it gives us a basis for calculating distributional weights (Somanathan, 2006). For example, suppose willingness to pay for a thirty-year extension to healthy life in the US is $5,000,000, and in India it is $250,000. Then $1 to an Indian has the same value as $20 to an American.

It is sometimes assumed that cost-benefit analysis is conducted against the background of efficient markets and an optimal redistributive taxation system, so that the distribution of income can be assumed to be ideal from the society's point of view. This is not an acceptable assumption for most projects aimed at climate change. In particular credit and risk-sharing markets are imperfect at the world level, global coordination is limited by agency problems, and there is no supra-national tax authority to reduce worldwide inequalities. Furthermore, intergenerational transfers are difficult and the mixed history of foreign aid suggests international transfers are also difficult. In any case, the power of taxation to redistribute income is limited by the fact that all practical taxation inevitably creates inefficiency (Mirrlees, 1971). Even optimal taxation would therefore not remove the need for distributional weights.

The need for these 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.[8]

[8] The method is presented in Drèze and Stern, (1987, pp. 909–989). Applications of distributional weights to climate change appear in Azar and Sterner, (1996); and Fankhauser, Tol, and Pearce,(1997).

3.5.3 The Paretian approach

The Paretian approach to valuation is motivated by the assumption that the wellbeings of different people cannot be compared, so no social welfare function exists. It does not require distributional weights.

The *Pareto criterion* tells us that one of the options in a decision problem is better than another if it is better for someone and at least as good for everyone (Arrow et al., 2002, p. 42). It is uncontroversial, but it does not yield a complete ordering of options – it does not rank all options. It provides only a sufficient condition for betterness, and it can rarely be applied directly in practical decision-making. Nevertheless, it does have one important implication for the economics of climate change. Since greenhouse gas creates an externality, it causes the world economy to be inefficient in a Pareto sense. This means it is technically possible to eliminate the externality in a way that is better for some people and at least as good for everyone. No sacrifice is required from anyone to eliminate the externality (Foley, 2009; Rezai et al., 2011). This point is often forgotten in international negotiations.

An alternative criterion is variously known as the *potential Pareto criterion*, the *compensation test* or the *Kaldor-Hicks criterion* (Hicks, 1939; Kaldor, 1939). Compare two options *A* and *B.* Suppose it would be possible, starting from *A* and simply by redistributing income or wealth among the people, to reach a state that is better than *B* according to the Pareto criterion. Then the potential Pareto criterion says that *A* is better than *B*. Imagine the economy moves from *B* to *A*. If the gainers from this move could fully compensate the losers in such a way that some people are made better off by the move and no one is made worse off, then *A* is better than *B* according to the potential Pareto criterion. This is so whether or not the compensation is actually paid.

The potential Pareto criterion is sometimes held to offer a basis for cost-benefit analysis, if benefits and costs are measured according to their compensating variations (CVs) and aggregated without any distributional weights. If the economy moves from *B* to *A*, gainers from the move have positive CVs and losers negative ones. If benefits exceed costs measured by CVs, the sum of all CVs is positive. This is held to show that the gainers could fully compensate the losers, so that *A* is better than *B* according to the potential Pareto criterion. But this Paretian basis for cost-benefit analysis is hard to justify, for the following reasons.[9]

First, a positive sum of CVs does not guarantee that the potential Pareto criterion is satisfied – that the gainers could fully compensate the losers. By definition, CVs are calculated at the prices prevailing after the move from *A* to *B* is made. If compensation was then actually paid, prices would change, and some people might consequently end up worse off (Boadway, 1982).

Second, for some pairs of options *A* and *B*, the potential Pareto criterion implies both that *A* is strictly better than *B* and that *B* is strictly better than *A* (De Scitovszky, 1941). This is a contradiction. It follows by *reductio ad absurdum* that the potential Pareto condition is false. A fix for this problem is to amend the criterion by specifying that it applies only to cases where the contradiction does not arise. The result is the so called *reversal criterion*, which says that *A* is better than *B* if, first, it is better according to the potential Pareto criterion and, second, *B* is not better than *A* according to the potential Pareto criterion (De Scitovszky, 1941).

However, third, for some triples of options *A*, *B* and *C*, the reversal criterion implies that *A* is better than *B*, *B* better than *C* and *C* better than *A* (Gorman, 1955). This cannot be true, so it follows by reductio ad absurdum that this reversal criterion is also false.

Fourth, the potential Pareto criterion has some incredible implications. Suppose a rich country proposes to emit greenhouse gas that would harm people around the world. Suppose it is willing to

[9] The difficulties are reviewed in Blackorby and Donaldson, (1990).

pay so much compensation to each victim that each would be willing to accept the harm in return for the compensation. Then the potential Pareto criterion implies that it would be better for the rich country to make this emission and cause the harm, rather than refrain from doing so, *even if it does not actually pay any compensation.* This is not credible.

3.6 Discounting future goods

Discounting allows economic costs and benefits incurred at different points in time to be compared. The relative valuation of economic and environmental assets with respect to time is crucial to decisions on how much sacrifice should be done today for the benefit of future generations. If one places little value on future changes in the availability of these assets (i.e., if one uses a large discount rate in CBA), the undertaking of actions and policies that involve current costs and future benefits will be difficult to justify using CBA. People do care when benefits and cost take place. The discount rate tells us how much one should do for the future. In climate change decisions, the choice of discount rates heavily affects the net present value of alternative policies.

This section discusses the literature on discounting. The discount rate may be viewed from a normative and from a positive perspective. The normative perspective involves determining what discount rate should be used for making long term decisions with regard to climate. The positive perspective focuses on how individuals and markets actually make intertemporal decisions, as revealed by the market interest rate. Both approaches can be relevant, depending on the application.

In CBA, in order to make things comparable across long periods of time, one values consumption changes in the future by equivalent changes in consumption today. The discount rate associated to this transformation corresponds to the rate of increase in the value of the corresponding asset over time. Different discount rates should be used for different assets (Malinvaud, 1953; Guesnerie, 2004; Sterner and Persson, 2008). For example, due to the anticipated increased relative scarcity of environmental assets, Gollier (2010) recommends using a 3% rate to discount economic impacts, but a much smaller 1% rate to discount environmental impacts.

The incorporation of the intergenerational equity objective has challenged the traditional CBA approach for the evaluation of climate change policies. CBA practitioners and evaluators must use discount rates that are consistent with the pre-specified social welfare function (SWF) that represents the Society's intergenerational values. To make this link clear, consider the representative bundle of commodities as a single aggregate good whose metrics is the GDP per capita in this homogeneous community. Let c_t denote the GDP/cap at date t. It yields a utility $u(c_t)$ for people living at that time. It is generally assumed that u is increasing (more consumption is better) and concave (the marginal utility of consumption is decreasing), as represented in the following graph.

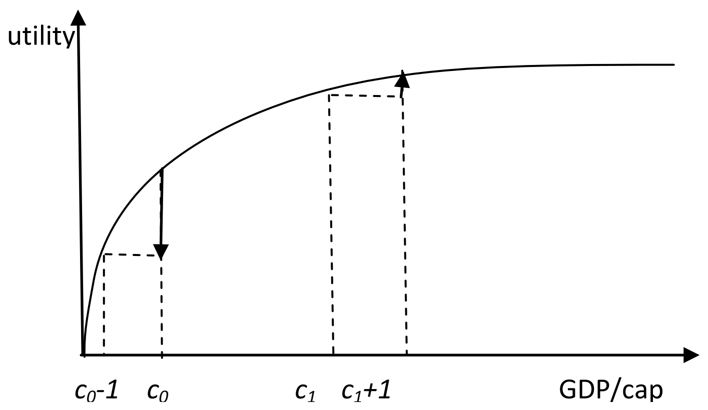

Figure 3.2. Transfer of one unit of consumption from present (0) to future (1)

Suppose then one expects future consumption c_1 to be larger than current consumption c_0, and consider an action that transfers one unit of consumption to the future. Figure 3.2 shows that this would reduce the intertemporal welfare, because it has a larger negative impact on current utility than a positive impact on future utility. This "wealth effect" comes from the combination of the two assumptions: (1) one is currently relatively poor and getting richer, and (2) poorer people have a larger marginal utility of consumption. This latter assumption implies that one is collectively averse to inequalities. This aversion to inequality implies that, in a growing economy, one will value more immediate increases in consumption than future increases in consumption. One will accept to invest for the future in spite of the increased intergenerational inequality that it generates only if the return of that investment is large enough to compensate for this welfare loss. The trade-off between consumption today and consumption in the future is the main economic justification of discounting.

Assuming a standard constant elasticity in consumption utility function (e.g., $u(c)=c^{1-\eta}/(1-\eta)$), this wealth effect is quantified in the Ramsey formula for the rate ρ_t to discount a sure increase in consumption in *t* years (Ramsey, 1928):

Equation 3.6. $\rho_t = \delta + \eta g_t$

δ is the rate at which the flow of future wellbeings is discounted. It is an ethical parameter that determines the relative weight of future generations in the welfare function. g_t is the annual growth rate of consumption anticipated until date *t,* and η is relative inequality aversion. The larger the economic growth rate g_t or the aversion η to inequality, the larger the discount rate ρ_t. The growth rate g_t is an empirical variable that represents our collective beliefs on economic growth, whereas the aversion η to inequality is a parameter that combines collective ethical attitudes (embedded in function *v*) and individual preferences (embedded in function *w*) contained in the utility function $u=v(w(c))$. In Box 3.2, we discuss plausible values for η.

The Ramsey formula assumes that the objective is to maximize the discounted total of utility (understood as wellbeing) over time. This is implicitly a version of utilitarianism. A corresponding prioritarian objective would be the discounted total of the *value* of wellbeing, taken to be a strictly concave transform of wellbeing. The Ramsey formula, and all the argument of this section, can be made consistent with prioritarianism by reinterpreting utility, u, as the value of wellbeing.

There is no consensus on the pure discount rate δ (Frederick et al., 2002). In the macroeconomic literature and in finance, a rate around 2% is often suggested (Skinner, 1989; Moore and Viscusi, 1990). Many authors have argued for a rate of zero (Ramsey, 1928, p. 543; Pigou, 1932, pp. 24–30; Harrod, 1949, p. 40; Parfit, 1986, pp. 480–486; Cowen, 1992; Broome, 2004, pp. 68–76; Stern, 2008, p. 35). Their argument is largely intuitive: it is simply implausible that people's wellbeing can be less valuable just because it occurs later in time. Cowen (1992) points 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). One argument is that it places an extremely heavy moral burden on the current generation (Dasgupta, 2007).

Box 3.2. Plausible values for collective inequality aversion

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. Contemplate an economic policy whose aim is to increase consumption by 1% of every person in the poor group. Because of the inherent inefficiencies of the tax system, this implies a reduction of consumption for every wealthy person by *x*%. If one is neutral to 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. A simple marginalist argument yields $\eta = lnx/ln2$ (Gollier, 2012). 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.

Different authors have taken different positions on the values of δ, η, and *g*, yielding different recommendation for the discount rate ρ. We summarize them in Table 3-1.

Table 3.1: Calibration of the discount rate based on the Ramsey rule (Eqn. 3.6)

Reference	δ	η	*g*	Implied discount rate
Weitzman (2007)	2%	2	2%	6%
Nordhaus (2008)	1%	2	2%	5%
Stern (2007)[10]	0.1%	1	1.3%	1.4%
UK: Green Book (2003)	1.5%	1	2%	3.5%*
US: OMB (2003)				7%
France: Rapport Lebègue (2005)	0%	2	2%	4%*

*Decreasing with the time horizon.

In Table 3.1, the Ramsey formula can be seen to yield a wide range of discount rates (1.4-7%) with a median of 4-5%. An alternative method to measure the efficient discount rate is based on a simple arbitrage argument. Rather than reducing consumption to finance additional investments, one can reallocate the productive capital of the economy in favour of these new projects. Because the wellbeing of current generations would be unaffected by this reallocation, such safe investments would be socially desirable if they raise the wellbeing of future generations. Obviously, this is the case if and only if their socioeconomic return exceeds the return of the risk-free capital of the economy, which is the equilibrium interest rate in a frictionless economy. Thus, the Ramsey formula should also be a predictor of the interest rate in the economy. However, the observed real interest rates in most developed countries over the last century have been much smaller than 4%, as shown in Table 3-2. Equity returns are documented in this table just for the sake of comparison, since this class of assets is risky so that their average return contains a risk premium (see Chapter 2). For our purpose, it would be most useful to estimate the real return of safe assets with maturities corresponding to the time horizons of investments linked to mitigating climate change. Bills have a maturity of less than 1 year, whereas the maturity of bonds used to build Table 3-2 is normalized to 10 years.

Table 3.2: Real return of financial assets

	Bills		Bonds		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%
Canada	1.6%	2.7%	2.0%	4.5%	6.3%	5.8%
Denmark	2.3%	3.5%	3.0%	7.0%	5.4%	9.0%
France	-2.9%	1.2%	-0.3%	6.6%	3.7%	7.8%
Italy	-3.8%	-0.3%	-1.8%	2.8%	2.6%	3.0%

[10] Stern(2007) does not use the marginalist approach that forms the basis of the discount rate. Rather, he relies on a SWF with the corresponding parameter.

	Bills		Bonds		Equity	
	1900-2006	1971-2006	1900-2006	1971-2006	1900-2006	1971-2006
Japan	-2.0%	0.4%	-1.3%	3.9%	4.5%	5.0%
Netherland	0.7%	1.8%	1.3%	3.9%	5.4%	8.5%
United Kingdom	1.0%	1.9%	1.3%	3.9%	5.6%	7.1%
Sweden	1.9%	2.4%	2.4%	4.2%	7.9%	11.0%
Switzerland	0.8%	0.4%	2.1%	2.8%	5.3%	6.1%
USA	1.0%	1.3%	1.9%	4.0%	6.6%	6.6%

Sources: Dimson, Marsh and Staunton (2002) and Gollier (2012)

The discrepancy between the prediction of interest rates from the Ramsey rule and observed interest rate is the risk-free rate puzzle (Weil, 1989). The puzzle comes from the inability of the theory under certainty to explain why people saved so much in the 20th century in spite of the low interest rates. 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. Under reasonable parameter values, Gollier (2008) shows that this precautionary effect reduces the discount rate by 1% for short time horizons and up to 3% for the distant future. Weitzman presented a calibration yielding a heavy tail for scenarios where GDP/cap tends to zero, yielding a negative discount rate (Weitzman, 2007 b). This result heavily relies on the controversial assumption that marginal utility tends to infinity when consumption tends to zero. More generally, if we accept the idea that marginal utility tends to infinity when consumption tends to zero, it is simple to justify a very low discount rate (potentially negative) for the distant future on the basis of facing a catastrophic scenario of human extinction with a small probability.

Due to differences in time and equity preferences, different countries may use different discount rates when credit and risk-sharing markets are incomplete, since they may also face differing levels of development and expectations about the growth of their economy. For example, using the Ramsey rule for recent high economic growth rates in China would yield a discount rate above 15% per year, whereas using it for some shrinking economies would generate a negative discount rate. This is another source of international disagreement about the strength of the mitigation effort. The global discount rate to be used to evaluate global actions will then depend upon how costs and benefits are allocated across countries. The discount rate described here should be used to discount risk-free costs and benefits.

3.7 Economics, rights and duties

This section examines linkages between economic theory and different types of ethical reasoning.   It lays a foundation for the discussion of equity and sustainable development in Chapter 4, and explains ethical and economic underpinnings for international agreements in Chapter 13 and climate change financing (Chapter 16).

3.7.1 Economic efficiency, equity and transfers

Economic theory generally assumes that considerations of equity can be separated from those of economic efficiency. Market outcomes corrected for externalities can achieve the efficient allocation of resources. Independently, the desired distribution of wealth or net costs can be achieved by way of transfers between individuals or nations (e.g. via taxes or tradable emissions permits), in line with principles of compensatory and distributive justice. The issue of *who* should bear the costs can therefore be separated from *where* mitigation takes place.

Conceptually, climate change mitigation among countries translates to determining emissions entitlements according to chosen equity principles, and then trading in entitlements in markets. Countries that use less than the amount of emissions they are entitled to receive a financial transfer, and countries that exceed their entitlements pay.

Equalizing the marginal cost of abatement with the marginal damage from climate change in turn is the fundamental condition for an economically efficient mitigation (Pigou, 1920). A precondition for achieving a given mitigation outcome at overall least cost is that the marginal cost of emissions reductions is equal across all emissions sources. This can be achieved if emissions entitlements are traded in undistorted markets, taking into account existing taxes and distortions(Babiker et al., 2002).

Trading of entitlements between nations have been regarded as a core element to achieve equitable and cost effective global mitigation (Stern et al., 2006; Garnaut, 2008; Stern, 2008). However, reliable systems of emissions accounting would be needed in all participating countries, and transfers may be subject to volatile prices and high transaction costs. Large scale international trade in emissions entitlements have been viewed as a potential source of financial instability (McKibbin and Wilcoxen, 2002), not to mention a source of political opposition (in net payer countries). An alternative are direct transfers between countries tied to specific mitigation investments (Chapters 13/16).

3.7.2 Types of costs and transfers

The practical application of the equity principles in section 3.2 principally relates to (1) costs of reducing emissions, (2) costs related to the adaptation to climate changes, and (3) damages to those affected by climate change.

Abatement. Financial transfers between countries for emissions entitlements may help pay for the costs of mitigation action in some countries. A large share of the global low cost emission abatement potential is in developing countries (REF from Ch6), and financial transfers could help pay for such carbon-reducing investments (Olbrisch et al., 2011) in countries that may otherwise not take these mitigation actions.

Adaptation. Responding to the impacts from climate change will in many instances require costly investments. In some low-income countries that are at risk of large climate change impacts, adaptation costs could be substantial relative to total economic activity (Fankhauser, 2010; Narain et al., 2011).

Compensation for impacts. Equity principles may support arguments for compensation from polluters to those affected by negative externalities (see earlier discussion in section 3.2).

3.7.3 Operationalizing equity principles for climate change mitigation

Normative interpretations of justice, equity and responsibility (see section 3.2) can be operationalized in different ways, implying different patterns of mitigation effort sharing and international transfers (Tol, 2001; Ringius et al., 2002; Heyward, 2007; Müller et al., 2009; Baer et al., 2009; Ekholm et al., 2010). There are no universally accepted principles to determine this choice. The use of equity arguments between nations and within societies may be self-serving (Lange et al., 2010). Disagreements are to be expected, given that the use of different principles and indicators can have strong implications for nations’ rights and responsibilities (Figure 3.3). For illustration, the basic effects are illustrated for four principles suggested by Ringius et al., (2002).

Egalitarian Principle: Each person is assigned an equal right to emissions at a point in time, or to an equal share in a global 'budget'(Messner et al., 2010) of greenhouse gas emissions. Responsibilities for mitigation can then be derived. An important factor is whether equal rights should be attained at some point in the future (such as under the 'contraction and convergence' proposal), apply from the present, or apply retrospectively and if so, from what starting date. This approach would generally ascribe less rights to emit and greater responsibility to mitigate to developed than to developing countries (Meyer and Hanmbock, 2004).

Ability to pay: The most frequently applied indicator is national income per capita, usually with differences in purchasing power taken into account (Rogoff, 1996; Bahmani-Oskooee and Hegerty, 2009).

The ability-to-pay principle can be operationalized as all countries devoting an equal share of their GDP to climate change action. More differentiated applications would require wealthier countries to pay a larger percentage of their GDP than poorer countries, or require countries to make a net contribution only if their per capita income is above a defined threshold. All would typically assign greater mitigation obligations to richer countries.

Ability-to-pay approaches can also be applied in the allocation of mitigation costs within nations, with cost incidence designed to fall predominantly on high income earners (Jotzo, 2012).

Polluter pays principle: According to the polluter pays principle, the party causing the pollution is responsible for paying for remediation or for compensating the damage. Applied as an equity principle for climate change mitigations, it would imply that responsibility for mitigation is proportional to past or present greenhouse gas emissions levels.

Sovereignty: The sovereignty principle takes the status quo as the basis for rights and duties for mitigation. It can be interpreted to imply equal percentage reduction of current emissions between nations, equal reductions relative to a baseline, constant shares for countries in global emissions or equalization of the marginal cost of emissions control.

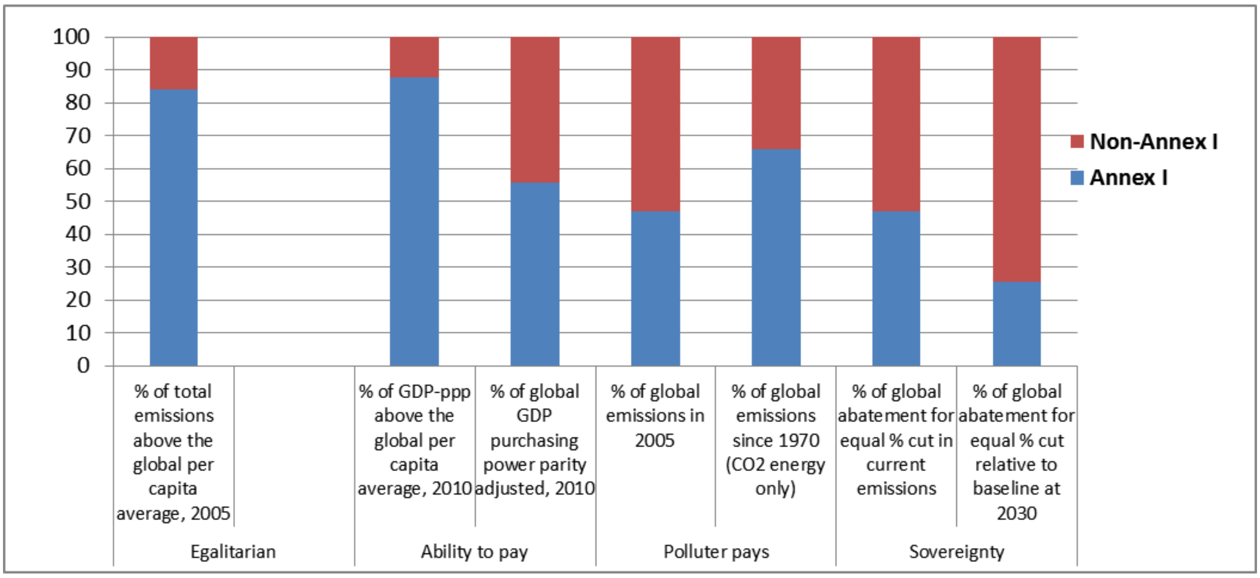

Figure 3.3 Quantitative Illustrations of Principles and Indicators. [AUTHOR: This figure is hypothetical. Goal is to replace it with something similar based on the literature.] Source: Bruvoll and Jotzo (2012)

The UN Framework Convention on Climate Change (1992) prominently recognized equity concerns in its principle of "Common but differentiated responsibilities and capabilities". Various aspects of rights and duties of nations pertaining to climate change action have been agreed, generally placing greater responsibility for action on developed countries (Box 3.3). These agreements do not however resolve the fundamental issues in operationalizing equity principles.

Box 3.3. Rights and duties agreed under the UNFCCC

The UN Framework Convention on Climate Change stipulates that the developed countries "should take the lead in combating climate change and the adverse effects thereof" (Article 3.1) and to assist developing countries to meet the costs of adaptation (Article 4.4). Developed countries are assigned the duty to provide finance and technology support to developing countries (Articles 4.3 and 4.5), and economic and social development and poverty eradication are recognized as "the first and overriding priorities" of developing countries (Article 4.7). The developed countries are also called on the provide "new and additional resources" for developing countries' mitigation programmes and adaptation measures (Articles 4.3 and 4.1), and to facilitate transfer of technologies

This principle of 'common but differentiated commitments and responsibilities' remains the subject of interpretation and negotiation (Honkonen, 2009), but it has been applied in a number of international agreements. Its first concrete expression was the dichotomous nature of the Kyoto Protocol, with quantitative emissions commitments only for industrialized countries (Grubb et al., 1999).

The on-going UN climate negotiations are aiming for an outcome that places mitigation obligations on all major emitters, though with differentiation in the extent of rights and responsibilities between them (Tollefson, 2012). Developed countries have pledged to provide large scale climate change finance to developing countries (Haites, 2011)

3.8 Policy instruments and regulations

This section synthesizes conceptual issues on policy instruments and the different contexts in which they are assessed or implemented. Policy instruments are understood as the key means or operational forms for achieving policy objectives (e.g. reduction of GHG emissions) and policy targets (i.e. a measurable indication of policy objectives). Policy instruments are often understood to have the effect of guiding social considerations targeted by public policy, providing incentives or disincentives and information.

3.8.1 Taxonomies and context specificity of policy instruments

Policy instruments can be categorized in several ways. First, one can categorize climate policy instruments depending on whether they directly or indirectly target GHG emissions. Direct policy instruments address and aim to reduce GHG emissions explicitly (e.g. carbon tax). Indirect instruments are other non-climate policies that are not specifically directed at GHG emissions ate policy instruments in particular, see reduction, but which may have significant climate-related effects like, for instance, reduction of GHG emissions due to increased energy efficiency or the promotion of renewable energy (e.g. through feed-in-tariffs, building codes).

Second, a different distinction is between price vs. quantity policies (Weitzman, 1974, 1978; for a recent discussion about climate policy instruments in particular, see Hepburn, 2006 and; Nordhaus, 2007) In this taxonomy, price policies include both emission taxes and abatement subsidies, because these policies fix the price per unit of pollution and allow the polluter to determine the quantity. In contrast, quantity policies include both permit systems and quotas, because both of these policies fix the total quantity of pollution (whether or not polluters can buy or sell those pollution rights). This distinction would not matter with perfect information, because a fixed price would lead to a known quantity (and vice versa) (Weitzman, 1974). However, in reality abatement costs and climate change damage costs are unknown in advance. Therefore the price policy may lead to a different quantity of pollution than anticipated, while the quantity policy leads to a different price of pollution (and marginal cost of abatement) from that anticipated (Montgomery, 1972; Weitzman, 1974; Roberts and Spence, 1976) Which of those uncertainties is more costly to society depends on the nature and uncertainties about climate change damages, mitigation costs, and business-as-usual emissions. This in turn determines the optimal choice of policy.[11]

Greenhouse gases are a stock pollutant, which a priori makes price based control more efficient under uncertainty (Pizer, 2002). However if benefits (avoided climate change damages) are extremely non-linear compared to mitigations costs, then quantity-based instruments may be more efficient (Nordhaus, 2007).

Nordhaus (2007) concludes that a carbon tax offers advantages compared to quantity-based instruments, as it can better incorporate the economic costs and benefits of emission reductions – moreover under the presence of high uncertainties. Likewise, Avi-Yonah and Uhlmann (2009) argue that a carbon tax, adjusted over time, is preferable to a cap-and-trade scheme because of its simplicity, certainty over cost-revenue, and clear message to polluters. However, the literature also acknowledges that the political acceptability of carbon taxes is low (e.g. Gupta et al., 2007).

'Hybrid' policies combining price and quantity control are likely to be superior. Roberts and Spence(1976) point out that under uncertainty a mix of price and quantity instruments is preferable to either pollution fees or restrictions on emissions. Weitzman (1978) argues that even if price and quantity policies are often treated as mutually exclusive, it is very unlikely that either option is optimal. Recent literature has discussed more complicated hybrid policies, where the policymakers are not merely choosing once and for all between a price policy like an emissions tax or a quantity policy like a permit system(Webster et al., 2010) .

Another common distinction is between market-based mechanisms and prescriptive (also known as command-and-control) regulation (see e.g. Oates et al., 1989; Portney and Stavins, 2000; Stavins, 2008). Market mechanisms include both emissions taxes and permit systems, because both of those policies establish a price per ton of emissions that provides individual polluters with an incentive to abate. In contrast, prescriptive regulation includes nontransferable emissions quotas, performance standards, and other mandates. . The key to the distinction between prescriptive and market regulationsis the level of discretion given to pollution sources to set their pollution discharges (market-based mechanisms give the most discretion). Whereas prescriptive regulations set pollution limits and/or technology, market mechanisms leave discretion to the regulated firm/source (cf. Oates et al., 1989)

Market mechanisms can minimize total abatement cost by allowing emitters to choose the cheapest forms of pollution abatement, where those emitters are merely trying to avoid paying the price per unit of emissions. Prescriptive approaches such as technology standards offer little flexibility in the means of meeting policy targets. Such lack of flexibility might require abatement technologies that are substantially more expensive. However, and depending on many factors (e.g. transaction costs), when marginal costs are similar among pollution sources the performance of prescriptive instruments might be comparable, or better than, market-based incentives (Cole and Grossman, 1999; Newell and Stavins, 2003). It is argued that a sound comparison between these options require that any extra benefit related to command-and-control policies be offset against the theoretical cost advantages of market-based instruments (Oates et al., 1989).

Based on the above-mentioned issues, the following sections elaborate on conceptual and theoretical aspects of three specific types of policy instruments. As noted above, the literature does acknowledge that it is sometimes difficult to separate or draw a clear line between these categories

[11] Setting the price might be very costly if a little additional pollution has severe costs such as lives lost (relatively steep marginal damages), or alternatively, setting the quantity might be very costly if achieving the required abatement turns out to be much more costly than expected (relatively steep marginal abatement costs).

of policy instruments.[12] Note that policy inaction can also be considered as another type of policy[13]. Policies can be designed and implemented to operate in different spatial and sectoral contexts. For details about applications and assessments, see Chapters 8-11 (sectoral level), Chapter 13 (international level) and Chapter 15 (national and sub-national level). For specific definitions, see Box 3.4.

Box 3.4 Definitions in the 4th Assessment Report on selected GHGs abatement policy instruments (Gupta et al., 2007, p. 750)

Regulations and Standards: These specify the abatement technologies (technology standard) or minimum requirements for pollution output (performance standard) that are necessary for reducing emissions.

Taxes and Charges*: A levy imposed on each unit of undesirable activity by a source.

Tradable Permits*: These are also known as marketable permits or cap-and-trade systems. This instrument establishes a limit on aggregate emissions by specified sources, requires each source to hold permits equal to its actual emissions, and allows permits to be traded among sources.

Voluntary Agreements: An agreement between a government authority and one or more private parties with the aim of achieving environmental objectives or improving environmental performance beyond compliance to regulated obligations. Not all VAs are truly voluntary; some include rewards and/or penalties associated with participating in the agreement or achieving the commitments.

Subsidies and Incentives*: Direct payments, tax reductions, price supports or the equivalent thereof from a government to an entity for implementing a practice or performing a specified action.

Information Instruments: Required public disclosure of environmentally related information, generally by industry to consumers. These include labelling programmes and rating and certification systems.

Research and Development (R&D): Activities that involve direct government funding and investment aimed at generating innovative approaches to mitigation and/or the physical and social infrastructure to reduce emissions. Examples of these are prizes and incentives for technological advances.

Non-Climate Policies: Other policies not specifically directed at emissions reduction, but which may have significant climate-related effects.

* Examples of economic instruments. R&D can also be incentivized using economic incentives.

3.8.2 Economic instruments

Economic instruments provide economic or fiscal incentives (or disincentives) that alter the conditions or behaviour of target participants. Economic instruments are regulations that encourage environmentally-friendly behaviour via price signals rather than mandated pollution control levels (Hahn and Stavins, 1991). This category covers a wide range of various policies including, for instance, carbon taxes, tradable allowances[14] or permits, tax exceptions, subsidies, soft loans,

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[12] For instance Hahn (2000, p. 376), defines an economic instrument as any policy instrument "that is expected to increased economic efficiency relative to the status quo". Thus, a command-and-control instrument can be classified as an economic instrument as long as it leads to improvements in economic efficiency.

[13] The political science literature acknowledges governmental inaction also as a policy, and focuses on the resources needed to implement public policies (Howlett, 1991; Vedung, 1998).

[14] The auctioning of emissions allowances and carbon taxes can raise large amounts of public revenues. For instance, the auctioning of allowances under the EU emission trading scheme is expected to generate £ 8

charges, public procurement, grants and insurance.[15] Many economic instruments of mitigation policy have fiscal implications, or are in fact instruments of fiscal policy (e.g. government funding, tax exceptions).

3.8.2.1 Prescriptive Approaches[16]

Prescriptive approaches refer to measures that require targeted participants to achieve certain environmental outcomes. Through legislation, public authorities enact laws or mandates that oblige various groups in society to attain targets or renounce performing certain activities (e.g., Cole and Grossman, 1999). These legal mandates are also called direct regulations or command-and-control approaches. These regulations may apply direct to GHG emissions or indirectly, such as building codes, fuel standards, minimum performance standards (technologies, facilities, houses), procurement regulations, and mandatory energy audits. Cases of non-compliance may incur legal penalties.

3.8.2.2 Information instruments

Informative instruments focus on the provision of information as crucial instruments to achieve or prevent social change. Informative instruments aim to increase the awareness of individuals with regard to consumption (and production) choices via education, media channels and labelling (Mont and Dalhammar, 2005). The logic behind these schemes is that market agents possess imperfect information, and better knowledge is needed to make good decisions. In particular, persuasion and increased awareness are assumed to allow people to behave in a more socially beneficial manner. Changes in perceived responsibility can generally affect behaviour and utility (Brekke et al., 2010). Information about climate change and the effects of instruments, and changes in policy, can influence the perception of moral behaviour and norms. Direct policy instruments include carbon labelling schemes and climate awareness raising campaigns for reducing GHG emissions. Indirect policy instruments include energy efficiency demonstration programmes, educational and advice centres, and training programmes for renewable energy. The effectiveness of information schemes may depend on the access and use of the information as such (Gupta et al., 2007).

3.8.2.3 Voluntary actions and agreements

Voluntary agreements generally involve a regulator and target industrial firms or sectors that commit to achieve a given objective. Firms participate if they perceive gains or no net losses (Alberini and Segerson, 2002). To be meaningful, the agreement aims to improve environmental conditions above current regulation (i.e. it is additional to what would have occurred under existing regulation), though it is unclear if such improvements occur. Voluntary agreements can arise via several ways, for instance, as a result of a negotiation between subject participants and the regulator. Another case may entail a spontaneous agreement within the private sector as form to avoid more stringent regulation in the future. In principle, this instrument aims to offer further

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Billions by 2020 (Kennedy et al., 2010, p. 383). In Sweden, carbon taxes have raised 2.4% of total tax revenue (Bosquet, 2000, p. 21).

[15] The literature on the interplay between disaster risk analysis and energy strategies highlight the role of insurance as market-based mechanism to loss-prevention benefits (Mills, 2003). The most widely discussed areas to introduce insurance are coastal flooding and the agriculture sector (Kunreuther, 2006; Stinchcombe, 2008). It is argued that in the field of climate change, cost-benefit analysis is likely to be dominated by considerations and conceptual aspects related more to catastrophe insurance than to the consumption effects of long-term discounting (Weitzman, 2009). For further details, see Chapter 2.

[16] Regulatory policy instruments are sometimes labelled as mandatory administrative or command-and-control instruments.

flexibility to parties subject to market-based instruments and regulatory approaches. The literature is ambiguous as to whether any additional environmental gains are obtained via voluntary agreements (Koehler, 2007; Lyon and Maxwell, 2007; Borck and Coglianese, 2009).

3.8.3 Policy interactions

Numerous policy instruments are adequate for different types of environmental problems in several contexts. Whereas the majority of the literature has been concerned with the use and assessment of one instrument, or comparison between alternative options, the reality shows a portfolio of instruments in operation. In fact, the multiple objectives surrounding climate change mitigation have been addressed through numerous of policy instruments.[17] Thus, the coexistence of different instruments creates synergies, overlaps and problematic interactions. However, the literature on ex-post evaluation of climate policy interaction remains limited (cf. Sorrell and Sijm, 2003; Bennear and Stavins, 2007) and the majority of studies focus on ex-ante assessments.

Within this context, one interaction often discussed refers to a carbon tax combined with a cap-and-trade scheme. In principle, there is no need for such a combination, as both instruments send exactly the same incentive to subject parties: polluters that can reduce their emission levels cheaply will invest in doing so. It is argued that the combination of these two instruments (price and quantity) decreases the carbon permit price without distorting incentives (Fankhauser et al., 2011).

Another policy interaction that has received attention in the literature relates to emissions trading and/or carbon/energy taxes with renewable energy and energy efficiency policy portfolios. Sorrell and Sjim (2003) argue that several instruments can simultaneously exist if they improve the economic efficiency of emission trading; however, as policy portfolios may also increase abatement costs with no additional emission reductions, policy objectives and corresponding trade-offs need to be explicit. For the particular case of emission trading interacting with tradable certificates for renewable energy, Morthorst (2001) concludes that the combination of both trading systems may yield net positive results if an emission trading scheme entails the auctioning of permits. Regarding the specific interaction between emissions trading and tradable certificates for energy efficiency instruments, Mundaca (2008) found that electricity savings resulting from the latter frees up allowances on the supply side creating, in principle, certificates in two different markets.

Another important type of interaction is between carbon policies and other environmental or non-environmental policies (Parry, 1997; Parry and Williams, 1999). A carbon tax or other policy may be enacted to reduce GHG emissions, but it may also increase or reduce other emissions. It may thus require changes in other non-carbon policies, such as sub-national restrictions on sulphur dioxide or other local pollutants. Any carbon policy may raise product prices and thus interact with other taxes that also raise product prices. Thus, it may be regressive unless the mechanisms of redistribution are adjusted to offset it. Since the excess burden of taxation rises more than proportionately with the size of the total tax, the carbon policy's addition to excess burden may be much larger if it is added into a system with other taxes on output or on inputs. Instead, economic efficiency can be enhanced by using a carbon tax or sale of permit revenue to reduce other distorting taxes.

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).[18] Parry

[17] A complete description on all the (potential) combinations of policy instruments can be found in sectoral Chapters (8-11) or policy assessment Chapters (13, 15 and 16).

[18] Note that two versions of the 'double dividend hypothesis' are found in the literature. One version (so-called 'strong hypothesis') implies that efficiency gains from diminishing distortionary taxes can more than compensate the costs of pollution taxes. Another version (so-called 'weak hypothesis') states that efficiency gains from reducing distortionary taxes compensate only part of the costs of pollution taxes (Goulder, 1995).

(1997) and Goulder et al. (1997) conclude that the implementation of a carbon tax or emission trading can increase the deadweight loss of pre-existing labour tax distortions; however, revenue collected 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 the costs and general welfare impacts of eight policy instruments to reduce carbon emissions; including energy taxes and performance standards. The authors conclude that pre-existing tax distortions raise the costs of all abatement policies, and that the superiority of carbon taxes or emissions trading depends on whether generated revenues can be directed to reduce other distortionary taxes.[19] As clarified by Goulder (1995), if existing income taxes reduce the real net wage and distort labour supply decisions, pollution taxes or restrictions such as quotas may raise output prices further, reduce the real net wage, and exacerbate the deadweight loss of taxes. That welfare cost may exceed the welfare gain from correcting the pollution externality (Fullerton and Metcalf, 2001). One lesson is that forgoing revenue raising opportunities from a greenhouse gas regulation can significantly increase the inefficiencies of that regulation. This is increasingly reflected in the practice of carbon pricing. The European Union is auctioning an increasing share of permits with revenue going to member states. Australia is using a large share of carbon pricing revenue to reduce income tax (Jotzo, 2012).

Policy interactions also create important implementation and enforcement challenges when policies are concurrently pursued by different legal or administrative jurisdictions (Goulder and Parry, 2008), like state and federal programmes in the context of US climate change policy (Goulder and Stavins, 2011).

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

Major differences between developing and developed countries' conditions and circumstances may lead to differences in the suitability and performance of policy instruments. Overriding policy objectives in developing countries tend to be strongly oriented toward facilitating development (Kok et al., 2008) or alleviating poverty as such (in least developed countries). In addition, the policy objectives and priorities may be different, as most developing countries are most concerned about education, health services, housing, and nutrition. However, as detailed in Chapters 4 and 14, strong synergies between development, economic and climate policies are found in the literature (e.g. rural electrification programmes with renewable energy technologies). Developing-country governments tend to rely more (relative to developed countries) on comprehensive development plans. These may incorporate climate-friendly principles.

Developing countries may also lack human and financial resources, advanced technology, and have poorer institutional and administrative capacity, which may affect or constrain their ability to evaluate, implement and enforce policies. Thus, the use of certain market mechanisms, such as carbon trading schemes, may not be suitable or effective, or require significant efforts for creating the institutional prerequisites. In addition, entrenched distortions in regulatory and pricing mechanisms may need reform before price-based instruments can be effective.

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 may need to be significantly higher than in developed countries in order for mitigation investment to be judged worthwhile. Thus, most developing countries may require significant international financial resources in order to support their mitigation activities or make them economically viable.

[19] Parry and Bento (2000) argue that a major drawback of the 'double dividend hypothesis' is that it ignores the interactions between environmental taxes and pre-existing taxes.[AUTHOR: need for further clarification]

Another difference is that while the private sector is a dominant force in developed countries, the public sector is more significant in many developing countries.[20] Thus, the state and its enterprises have an important role in direct economic activities, especially in electricity, energy, infrastructure, and transportation. The role of public investment as an instrument (e.g. via fiscal policies) might be critical in developing countries, buy may lack of needed financial resources. Whereas developed countries may give a greater role to market mechanisms, taxes, and regulations, developing countries may emphasize public investment and industrial policies managed by the State (UN-DESA, 2009). Thus, reducing GHG emissions may require coordinating interconnected public investments.

3.9 Assessing methods of policy choice

Policy evaluation refers to the "process of determining the merit, worth or value of something or the product of that process (Scriven, 1991, p. 191).[21] It is the systematic application of social research procedures to assess the design, choice, and implementation of policy (Majchrzak, 1984; Rossi et al., 2004). Most importantly, the choice of specific climate policy instrument (or mix of instruments) depends upon many economic, social, institutional, and political contexts. The tasks undertaken to determine climate policy goals and policy instruments are frequently conducted in the presence of significant complexity and uncertainty (e.g. long-term costs and benefits of climate impacts).

3.9.1 Policy objectives and evaluation criteria

In addition to reducing GHG emissions, climate policy may have many other objectives. Here, we organize these many objectives into four broad categories.[22] First, climate policy may have economic objectives that involve lowering economic costs, including transactions costs, losses in economic efficiency, and any adverse effects on economic development, innovation, and growth. Second, climate policy may have distributional objectives. It may need to avoid interfering with goals to alleviate poverty, if it is to be viewed as fair. These distributional considerations are often decisive in the political sphere. Third, climate policy can have multiple environmental objectives at the local, regional, and global levels. Fourth, climate policy will need to be institutionally feasible for it to be adopted, in terms of administrative burden and other political considerations.[23]

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[20] The principles of cost-effective environmental policy can also be applied to mixed economies with major public enterprises. If the managers of those public enterprises make resource allocation decisions directly, without price incentives, then economic efficiency requires that each manager be told their carbon abatement target. Alternatively, public enterprises may be operating in an economy where private enterprises do face a carbon tax. In this case, an alternative way to implement cost-effective environmental policy is just to let those public enterprise managers use their own budgets. However, one must consider that incentives may be different in public enterprises and thus policy instruments may not work as expected.

[21] The literature on policy evaluation is vast. For comprehensive overviews of history, theories, views and influences in the field of evaluation see e.g. Alkin (2004), Pawson and Tilley (1997), Bardach (2011), and Chen (1990).

[22] The 3rd IPCC Assessment Report acknowledged many evaluation criteria but emphasized cost-effectiveness (see Bashmakov et al., 2001). The 4th IPCC Assessment Report broadened the scope; it emphasized the four dimensions of performance we use in this subsection (see Gupta et al., 2007). Here, we elaborate further.

[23] Political factors have often been more important than economic ones in explaining instrument choice (Hepburn, 2006). Existing industries have influenced policy to ensure that a large number of permits are allocated free to emitters (Smith et al., 1983); (Pezzey et al., 2010). Revenue can be used to achieve desired distributional outcomes and to offset adverse effects on employment (Freebairn, 2011). Redistribution to low-income households is an important feature in Australia's emissions pricing, along with features such as emissions price controls that reflect preferences of different groups in society (Jotzo and Hatfield-Dodds, 2011).

Any policy option then can be evaluated by the extent to which it meets each of these policy objectives. That is, the list of "evaluation criteria" is the same as the list of policy objectives: does the policy appropriately balance economic costs, distributional considerations and environmental objectives in a way that is institutionally feasible? However, the relative importance of the different policy objectives is likely to differ among countries, especially between developed and developing countries. Each country has its own conditions, circumstances, and national priorities. While all objectives discussed here are relevant, different countries may apply different weights to them.

In this section, we discuss elements of those four categories of policy objectives and criteria. In doing so, we expand upon recent policy evaluation studies, leaving more details to Chapters 13-15. In fact, the literature stresses a broad variety of objectives and criteria (e.g. Opschoor and Turner, 1994; Faure and Skogh, 2003; Sterner, 2003; Mickwitz, 2003); Blok, (2007); and Ostrom, (1999).

The basic economic framework for policy analysis can be depicted using a simple partial equilibrium diagram from Fullerton (2011). This diagram (Fig 3.4) illustrates both the impacts of policies and the criteria to evaluate them. To introduce the topic and focus on basic concepts, we initially abstract from various forms of complexity.

As shown in Figure 3.4, the quantity of GHG emissions associated with production of 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 those emissions is derived from the demand for electricity, as shown by the curve called Private Marginal Benefits (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 of climate change, however, and so each unit of output has a Social Marginal Cost (SMC) measured by the vertical sum of Private Marginal Cost (PMC) plus Marginal External Cost (MEC).

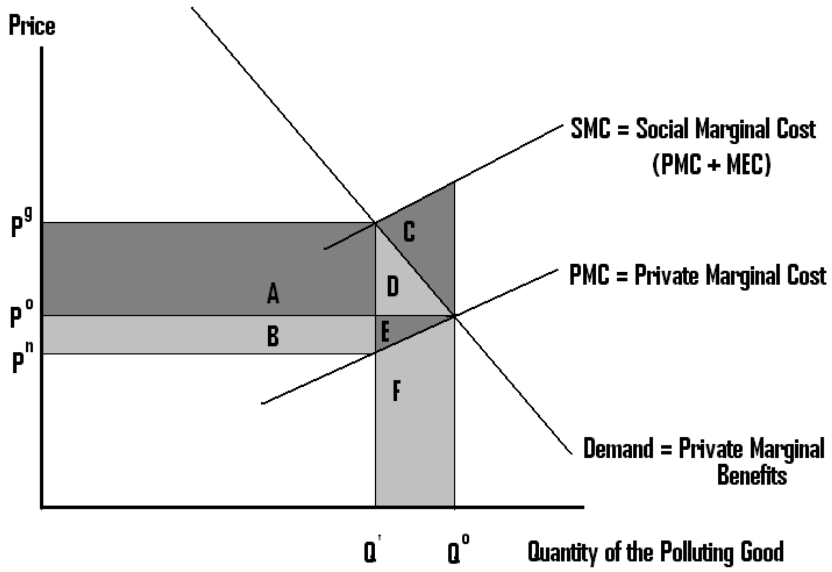

Figure 3.4 A partial equilibrium model of the costs and benefits of a market output

Assumptions of the simplest version of this model can be relaxed and discussed below but for now include perfect competition, perfect information, perfect mobility, and many identical consumers (so all individuals equally benefit from production of electricity, and they equally bear the external cost of pollution). Then the social optimum production is where SMC=SMB, at Q'. The first point of this diagram, then, is that the optimal quantity can be achieved by several different kinds of policies under these simple conditions. A simple regulatory quota could restrict output to Q', or a fixed number of tradable permits could restrict pollution to the quantity Q'. In that case, P^n is the equilibrium price *net* of permit cost (the price received by the firm), while P^g is the price *gross* of permit cost (paid by the consumer). The permit price is the difference, P^g - P^n. Alternatively, a tax of (P^g - P^n) 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, and it will be used to show gains and losses to various groups.

3.9.1.1 Economic Objectives

Economic efficiency. A reallocation of resources improves economic efficiency if the sum of the gains outweighs the sum of the losses (see the Potential Pareto Criterion discussed in section 3.4.3).[24] In Figure 3.4, any reduction of output from Q^0 improves efficiency, because it saves costs (height of SMC) that exceed the benefits of that output (height of SMB). Further reductions of 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 in that diagram. An element of economic efficiency across time is the extent to which a policy encourages the right amount of investment in the future, including research, innovation, technical change, development, dissemination and commercialisation of low-carbon technologies (Jung et al., 1996; Mundaca and Neij, 2009).

Cost-effectiveness. Pollution per unit of output in Figure 3.4 is fixed, but actual technologies allow many different ways to reduce pollution per unit of output. Some policies may require expensive means of reducing pollution per unit of output. A policy is more cost-effective if it achieves a given pollution abatement at lower cost. A critical condition for cost-effectiveness is that marginal compliance costs be equal among obliged parties.[25]

Transaction costs. In addition to the price paid or received, market actors face other costs to initiate and complete transactions -- including the costs of search for information, due diligence, negotiation of contracts, and measurement. These costs alter the relative effectiveness of different policies.[26]

3.9.1.2 Distributional objectives

Six distributional effects. Because individuals are *not* all identical, 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 social welfare function, as discussed in section 3.3.5 . These distributional effects fall into six categories (Fullerton, 2011). In Figure 3.4, any policy instrument might reduce the quantity of polluting output, such as from Q^0 to Q', which reduces the polluting emissions, raises the equilibrium price paid by consumers (from P^0 to

[24] A reallocation is a "Pareto Improvement" if somebody is better off while nobody is worse off. But no realistic policy change can avoid making anybody worse off (Stavins, 2004). A more realistic approach might identify a "Potential Pareto Improvement" as a change with gains that exceed losses, so that those who gain could compensate those who lose (the 'Kaldor-Hicks' criterion). If all consumers are identical, as in the simplest model, then all share in the net gain. This framework is a possible foundation of cost-benefit analysis (CBA), an operational and pragmatic approach to economic efficiency. In practice, of course, CBA can be ambitious, challenging, and sometimes impracticable, because it requires intensive data collection, assessment, and processing (see e.g. Sterner, 2003; Harrington et al., 2004; Tietenberg, 2006).

[25] Overall economic efficiency requires two conditions, assuming there are no other distortions. First, the policy must be cost-effective, minimizing the cost of a given abatement. Second, an efficient policy also requires the optimal amount of abatement.

[26] In particular, this criterion often examines "the costs of arranging a contract *ex ante* and monitoring and enforcing it *ex post*, as opposed to production costs" (Matthews, 1986, p. 906).

P^g), and reduces the price received by the firms (from P^0 to P^n). It thus has six effects illustrated in Box 3.5.

Box 3.5. Six Distributional Effects of Climate Policy, illustrated for Coal-Fired Electricity

(1) The policy raises the cost of generating electricity and thus the consumer's price (from P^0 to P^g), so it reduces consumer surplus. In Figure 3.4, the loss to consumers is the sum of area A+D. Losses are greater for those who spend a relatively high fraction of income on electricity.

(2) It reduces the net price received by the firm (from P^0 to P^n), so it reduces producer surplus by the sum of area 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.

(3) Pollution and output are restricted, so the policy generates "scarcity rents" such as the value of a restricted number of permits (area A+B). If those permits are handed out to firms, these rents accrue to shareholders. The government could capture these rents by selling the permits or if the policy is a tax per unit of emissions (Fullerton and Metcalf, 2001).

(4) Because the policy restricts greenhouse gas emissions, it confers benefits to those who would otherwise suffer from climate change. The value of those benefits is area C+D+E.

(5) The electricity sector employs less labour, capital, and other resources. It no longer pays them (areas E+F). With perfect mobility, these factors are immediately re-employed elsewhere, with no loss. With imperfect mobility, however, those workers may suffer substantial social cost.

(6) Any gain or loss described above can be capitalized into asset prices, with large immediate effects on current owners. The value of a corporation's stock may rise by the expected present value of future scarcity rents; the value of a person's waterfront home may fall by the expected present value of sea level rise (or rise by a policy that protects it).

The connection between these distributional effects and "economic efficiency" can be noted 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; the environmental gain is C+D+E. The net sum of those gains and losses is just area C, described above as the net gain in economic efficiency.

Referring to Box 3.5, and regarding the first effect on consumers, carbon policy is generally found to be regressive (though most analyses are for developed countries), because the higher price of electricity would impose bigger proportional burdens on lower income groups who spend higher fractions of income on electricity (Metcalf, 1999). The second effect, on factors of production, is generally ambiguous. The third effect is regressive if permits are handed out 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, then it can use the funds to help offset burdens on low-income consumers and make the overall effect progressive instead of regressive. Other effects are quite difficult to measure.

A major literature studies "environmental justice", the potential effects of pollution policy on different neighbourhoods with residents from different income or ethnic groups (Sieg et al., 2004). This issue focuses on how climate policy affects pollution in particular neighbourhoods. Climate policy affects not only GHG emissions but other local pollutants such as SO_2 or NO_X, whose concentrations can vary widely in space. 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 through sea level rise).

The distributional impacts of policies include aspects such as fairness and 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. For a comparative analysis of the 'optimal' distribution of costs and benefits, see (e.g. Feldstein, 1972).

3.9.1.3 Environmental objectives

Environmental effectiveness. A policy is environmentally effective to the extent 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 3.4), but actual policies differ in terms of enforcement, administration, and compliance.

Co-Benefits. Climate policy may reduce not only GHG emissions but also local and regional pollutants such as SO_2 emissions that cause acid rain or NO_X emissions that contribute to ozone. These reductions in other pollutants do not yield any net gain to society if those other pollutants are already optimally regulated (where their marginal abatement costs are equated to their marginal damages). If those pollutants are inefficiently regulated, however, then climate regulations can yield co-benefits in the form of net social gains from reductions of other pollutants.

Climate policy is also likely to affect other national objectives, such as energy security. For a country that wants to reduce dependence on imported fossil fuels, climate policy can bolster energy efficiency and domestic renewable energy supply, even while cutting GHG emissions.

3.9.1.4 Institutional feasibility

Administrative burden. Part of "institutional feasibility" is the extent of administrative workload, both for public authorities and for regulated entities. These human and financial costs depend on how the policy is implemented, monitored, and enforced (Nordhaus and Danish, 2003). This burden is related to the complexity of the institutional framework, the policy objectives, the number of regulated firms, and the accessibility of necessary data about these firms. Administrative costs matter in public policy, but they are often overlooked (which generates evaluation biases).

Political feasibility. Another part of institutional feasibility is the extent to which the policy is "viewed as legitimate, gain acceptance, adopted and implemented" (Gupta et al., 2007, p. 785). This criterion focuses on obstacles that hamper or enhance the political viability of a policy instrument. It aims to identify key design elements that can generate or reduce resistance among political parties (Nordhaus and Danish, 2003). Political feasibility may also depend on environmental effectiveness, costs, and how equitably the regulatory costs burden is distributed across society.[27]

Ex ante, all these criteria can be used to help understand the effects of policies, improve their design, and assess which policies can achieve outcomes that would justify their implementation. *Ex post*, these criteria can be used to verify results, to withdraw inefficient policies, or to provide corrections to improve performance of policy. Different policies perform differently on these four evaluative criteria. Chapters 14 and 15 summarize performance of different instruments on the basis of these four criteria. A similar table was presented in AR4 (Table 13.1 of WGIII). [AUTHOR: Plan to include table here].

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3.9.2 Analytical methods for decision support

Previous assessment reports have addressed analytical methods to support decision-making, including both numerical and case-based methods. Bruce et al. (1996), Chapter 2 and 10, focus heavily on quantitative methods and Integrated Assessment Models (IAM). In Metz et al. (Metz et al., 2001), Chapter 10 provides a wider review of approaches, including emerging participatory forms

[27] A critical issue when considering administrative burden and political feasibility is whether policy makers choose the most suitable institution to handle the policy's implementation and enforcement (Rist, 1998).

of decision-making. In Metz et al. (2007), Chapter 2 briefly elaborates on quantitative methods and lists sociological analytical frameworks.

3.9.2.1 Quantitative-oriented approaches

To assist decision-making processes, quantitative methods can organize and manage numerical information, provide structured analytical frameworks, and generate alternative scenarios – with different levels of uncertainty (cf. Majchrzak, 1984). Important challenges include measurement, causality, generalization, and replication (Bryman, 2004).

One specific quantitative approach is Cost-Benefit Analysis (CBA), as discussed above. CBA attempts to estimate and aggregate monetized values of all costs and benefits that could result from a policy. It may require estimating non-market values, and choosing a discount rate to express all costs and benefits in present value. An overall CBA could help identify a specific amount of pollution abatement as well as an efficient way to achieve it. When benefits are difficult to estimate in monetary terms, however, then a Cost-Effectiveness Analysis (CEA) may be preferable. A CEA can compare the costs of different policy options (Tietenberg, 2006) in achieving a well-defined goal. CEA can estimate and identify the lowest possible compliance costs, generating a ranking of policy alternatives (Levin and McEwan, 2001). Otherwise, CEA and CBA have similar limitations with respect to data, measurement, and valuation of future intangible costs.

Various types of models may help provide information for Cost-Benefit Analysis, including energy-economy-environment (E^3) models that study energy systems and transitions towards more sustainable technology. Two methodologies for modelling E^3 system interactions are “bottom-up” and “top-down” approaches. Hybrids of these two approaches can compensate for some known limitations (Rivers and Jaccard, 2006):

- 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 and may overlook critical market imperfections such as transaction costs and information asymmetries (Craig et al., 2002; e.g. De Canio, 2003; Greening and Bernow, 2004).
- In contrast, “top-down” models 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. They are often calibrated based on real data from the economy. However, such models may be too aggregated for some applications (Hourcade et al., 2006). Parameters are estimated from historical data, so forecasts may not predict a future that is fundamentally different from past experience, though that is a tall order for any model (Scheraga, 1994).

Multi-Criteria Analysis (MCA) is an approach that arises from the sheer number of evaluation criteria listed above (Greening and Bernow, 2004); it attempts to assess and compare the impacts and potential outcomes from competing policies (Mundaca and Neij, 2009). Some argue that the analysis of environmental and energy policies is a multi-criteria problem, entailing numerous decision makers with diverse objectives and levels of understanding of the science and complexity of analytical tools (Greening and Bernow, 2004). However, even with MCA, one must ultimately determine the appropriate tradeoff rates among the different objectives. MCA often leads to complex analysis of trade-offs (Sterner, 2003). The literature also stresses complexities of choosing and justifying weighting and aggregation methods (Munda, 2005).

Integrated Assessment Models (IAM) are a form of top-down model (see also Chapter 6). Using insights from different disciplines, IAMs include complex relationships between atmospheric composition, climate and sea level, human activities, and ecosystem functions (Weyant et al., 1996).

They can incorporate connections and feedbacks that allow examination of future paths of both natural and human systems (Morgan and Dowlatabadi, 1996). Also, computational limits may preclude the scales required for some climatic processes (Donner and Large, 2008).

General equilibrium and other computational 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 by 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 (Metcalf, 1999). A significant challenge is the definition of a 'welfare baseline' (i.e. what would be each welfare level in the absence of the policy).

Other quantitative-oriented approaches to support policy evaluation include tolerable windows (Bruckner et al., 1999), safe-landing/guard rail (Alcamo and Kreileman, 1996), portfolio theory (Howarth, 1996), and other standard methods of public finance.

3.9.2.2 Qualitative-oriented approaches

Various qualitative policy evaluation approaches focus on social, ethical, and cultural dimensions of climate policy. They might complement quantitative economics 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 seek to examine human behaviour related to climate change (Blumer, 1956), including beliefs, attitudes, values, norms, and social structures (Rosa and Dietz, 1998). Focus groups can capture the fact that "individuals' attitudes and beliefs do not form in a vacuum: 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 various actors actively participating in a given decision-making process (van den Hove, 2000). Participatory approaches to support decision-making include Appreciation-Influence-Control (AIC), Goal Oriented Project Planning (GOPP), Participatory Rural Appraisal (PRA), and Beneficiary Assessment (BA). For pros and cons of various 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).

3.10 Metrics of costs and benefits

Climate change will affect people in different ways. Some people may benefit; others may be harmed. In some cases, it is their livelihood that is affected; in others, it is their health, access to food or clean water, amenity of life, or the natural environment around them. Similarly, mitigation will impose costs on some groups of people but not others.

3.10.1 Measuring individual values

Many different metrics have been proposed. Some are anthropocentric (i.e., they characterize outcomes purely from a human perspective), while others are non-anthropocentric, such as measuring ecosystem integrity as an object of intrinsic value. Some metrics are monetary (willingness to pay, willingness to accept), while others are physical (non-monetary). Some metrics are inherently subjective, reflecting the preferences of an individual or a group, while others are objective and preference-independent. Changes in the numbers of people at risk for hunger, infectious disease, coastal flooding, or water scarcity are examples of non-monetary, anthropocentric metrics that can be seen as preference-independent. People's willingness to pay to avoid an increase in the risk of hunger or infectious disease, etc., is an example of an anthropocentric metric that is monetary and preference-based. Changes in the biodiversity or net primary productivity of an ecosystem are examples of objective, non-monetary metrics that are non-anthropocentric.

A change in a subjective anthropocentric metric implies a change in wellbeing, as seen by individuals whose preferences are reflected in the metric. The standard approach in economics measures wellbeing in monetary terms through a monetary *equivalence* – that is, through the monetary amount that is equivalent, in terms of its effect on the person's wellbeing, to the item in question. Logically there are two possible ways to formulate equivalence: the most that the person would be willing to pay to obtain the item (the *WTP* measure of equivalence); and the minimum compensation that the person would be willing to accept to forego the item (the *WTA* measure). The item in question may be a marketed commodity, but it need not be: it can be *anything* that the person values.[28] Thus, economic value is defined in terms of a tradeoff: it is how much money a person *would exchange for the item being valued, if she could*.

There are also anthropocentric but non-monetary metrics, including the Human Development Index (HDI) used as a metric of wellbeing across countries with different levels of economic development, based on life expectancy, education, and income (UNDP, 2010). This and related metrics (Dervis and Klugman, 2011) were motivated by the work of Sen (1999), who argued that what matters most for wellbeing is the opportunity and ability to live a good life, and that this results from the *capabilities* that people have, such as the ability to live to old age, to have a good job, to have freedom of choice, etc.

Since climate change affects people in different ways, multiple metrics of costs and benefits might be employed. For example, Schneider et al. (2000) advocated the use of a suite of five metrics: (1) monetary loss, (2) loss of life, (3) quality of life (including coercion to migrate, conflict over resources, cultural diversity, loss of cultural heritage sites, etc.), (4) species or biodiversity loss, and (5) distribution/equity. Only one of those metrics is monetary, and some, but not all, are preference based and/or anthropocentric.

3.10.2 The Costs of Mitigating GHGs

If GHG emissions are to be reduced, economic costs will be imposed on many actors, including firms, households and governments. These costs may take the form of changes in prices and costs, changes in revenue and net income, changes in the quality of commodities and changes in the availability of commodities. Reducing GHG is not totally a technological issue. In fact, behavioral changes and substitutions choices frequently are a major way in which GHG emissions are reduced. Whatever their form, these changes will lead to changes in wellbeing. As with other economic measurement, the changes in wellbeing are measured conceptually by the change in income that is equivalent in terms of the impact on the actor's wellbeing using the WTP or WTA measures.[29]

The changes in prices, costs, incomes, etc. are typically projected through the use of an economic model. These models are discussed in section 3.8 [AUTHOR: need to avoid repetition between 3.8 and 3.9] and in more detail in Chapter 6; here we provide a brief general overview. In many countries, mitigation primarily involves change in the generation and use of energy from fossil-fuels

[28] The economic concept of value was first applied to marketed commodities and later extended more generally to include non-market items. If the item is not obtainable through a market, the WTP equivalent should be seen as a thought-experiment.

[29] For a pure and small change in income, there is no difference between the WTP and WTA measures. For the other changes, the WTP and WTA measures are generally expected to be somewhat different unless the changes are very small and entirely marginal. Where they do differ, the WTP measure is generally expected to be somewhat smaller than the WTA measure (Willig, 1976; Hanemann, 1991). The climate economics literature commonly focuses on the WTP measure.

so as to reduce GHG emissions.[30] The initial economic effect is an increase in the cost of energy and a change in the pattern of energy supply and demand. However, these changes then reverberate throughout the economy: fossil-fuel intensive commodities become more expensive, leading to a drop in demand; non-fossil-fuel intensive substitutes become more attractive, leading to an increase in their supply and their demand. Different economic models capture different aspects of these changes. Partial equilibrium (PE) models focus narrowly on the energy-related sectors of the economy. Computable general equilibrium (CGE) models cover all the sectors of the economy and track the interactions among them, thus allowing for indirect effects elsewhere in the economy resulting from direct changes in the energy sectors. PE and CGE models typically represent economic equilibrium at a point in time. Growth models focus on the growth of an economy over time, driven by the allocation of output to investment versus consumption in each period, while typically eschewing a detailed sectoral decomposition of production. These models track the impact of economic production on GHG emissions, but many of them do not have a link to climate: climate conditions do not affect economic activity in most PE and CGE models.[31] However, some models, known as integrated assessment models (IAMs), do have a climate feedback component in which today's emissions endogenously generate changes in future climate.

Despite the differences among models, some general observations apply. While the degree of disaggregation by economic sectors varies, all the models are highly aggregated economically, socially and spatially. Non-energy sectors of the economy (and sometimes energy sectors) are represented in an aggregated manner as though there were a single representative firm. The households in the economy are typically represented as though there were a single representative consumer. The smallest spatial unit is typically a country or a group of countries. The aggregation obviates analysis of distributional issues. The models are calibrated to actual economic data, but they are not validated in the sense of generating predictions (or backcasts) of responses to specific stimuli and testing those predictions against actual outcomes.[32] One factor that would complicate such validation is that these are equilibrium models, which assume essentially instantaneous adjustment to changes in economic variables; most models do not address the speed of adjustment or incorporate a cost of adjustment.[33] Except for growth models, the models are quite static. In most models, the cost of abating emissions at a given time is independent of whether abatement has occurred previously, or how much; the cost just depends on the amount of abatement undertaken that year.[34]

[30] Some models focus just on CO2 emissions; other consider multiple gasses which are represented as tons of CO2-equivalent. Representing gasses with different climate impacts over different time scales through a single metric is itself an exercise in aggregation; the methodologies used to do this are discussed in section 3.6.3.

[31] Climate is assumed to be separable from market goods in the utility function underlying these models. Carbone and Smith (2012) show that there can be significant economic consequences if this assumption is relaxed.

[32] The models are often re-calibrated at periodic intervals based on new scientific information and/or recent economic changes not incorporated in preceding versions of the model (Howes et al., 2011).

[33] What the models tend to show, as Barker and Jenkins (2007) note, is "long-run responses often for undefined dates in the future." This becomes less of an issue to the extent that the unit of time in the model covers a longer span of years, such as a decade. The timing of the turnover of capital stocks is a factor in the speed of adjustment that is not well accounted for in most of the models. In fact, models often convert capital costs into an equivalent annualized cost, thereby erasing the distinction between funding operating costs and financing capital investment.

[34] This implies that abatement can be stopped and started costlessly.

The conclusions resulting from the models depend on the assumptions made (1) in specifying the model's structure and (2) in calibrating the model's parameters.[35] A key determinant of the economic cost of limiting GHG emissions is the feasibility and future cost of using non-fossil fuel energy in electricity generation and in transportation. Another is the feasibility and cost of increasing energy efficiency in end uses. Both of these depend crucially on the possibilities for technological innovation. They also have a behavioural component – whether or not actors will abandon old habits of behaviour and take up new technologies. Both are hard to predict and to model. They are often modeled in combination as an exogenous (autonomous) improvement in energy efficiency (AEEI) over time, which can represent both technological and structural changes. Another representation is through a backstop technology that causes significantly lower GHG emissions at a significant cost and stands available for adoption whenever economic conditions might warrant it. Whereas AEEI generally signifies incremental technological progress, the backstop technology can represent a technological discontinuity. In addition, there has recently been interest in making technological change an endogenous response to rising energy prices and/or targeted investments in R&D. Refer to section 3.11 for a discussion of technological change. It is fair to say that technological innovation is a complex and nuanced process that is not yet well represented in the economic models.[36]

The model conclusions also depend on the assumptions made about the economic policies employed in response to the limits on GHG emissions. Examples of factors that affect the economic cost of mitigation include whether countries act unilaterally or in coordination; whether emission trading is employed and, if so, whether this functions domestically or globally; what other distortions exist in the economy (e.g., subsidies for fossil fuel production); and how governments deploy revenues, whether from a carbon tax or the sale of carbon emission permits, and whether those revenues are used to reduce other taxes that cause distortions in the economy.[37]

The economic models generally involve an assumption of fully optimizing behaviour by economic agents. Therefore, aside from technological change, any reduction in emissions must be driven by changes in price.[38] In these models, there is no scope for behavioural factors such as a change in the norms held by consumers, a change in the business models used by companies, the emergence of new intermediaries or new industries. Behavioural factors lower the efficiency of the economy but,

[35] The two are interrelated since the calibration can offset some aspects of the specification (Fischer and Morgenstern, 2006).

[36] Technological change is discussed in section 3.11, which notes three stages in the process of technological change: the invention of a new product or process, innovation (when it is commercialized), and diffusion (when it comes to be widely used through adoption by many firms or individuals). Economic models often represent technological change as though there were a single actor handling all three stages (e.g., a firm chooses whether to invest in R&D and then whether to adopt the new technology). However, different actors are typically involved at each stage. There is a coordination problem, as well as the problem of spillover benefits accruing to other players from the knowledge externality. These are not typically reflected in the economic models used to analyze mitigation costs.

[37] The deployment of those revenues could also be used to deal with equity issues, either within or between counties.

[38]The connection is this: if agents are optimizing fully and there is no technological change, the only way to induce a change in their behaviour is by changing prices. Otherwise they would be doing something that they had formerly rejected, which must entail a welfare loss. However, in the US there was a large reduction in sulphur dioxide emissions between 1995 and 2000, and factors other than price signals and technological change played an important role (Burtraw, 1996; Burtraw et al., 2005). Rather than there being a response according to existing demand and supply curves, Hanemann (2010) argues that the main response was due to changes that are not captured by conventional CGE models. The extent to which something similar could happen with GHG mitigation is an open question.

as explained in section 3.7.1., they might also create some scope for interventions that could lower the cost of changing towards a less carbon-intensive economy.[39]

The models use various metrics to characterize the economic cost of GHG mitigation. Some models use the income-equivalent WTP measure. Another measure is the change in national income, measured by GDP. However, in national income accounts GDP includes government, investment and net exports as well as consumption, so this is not an ideal welfare measure; the change in consumption is a closer measure of welfare change. Another measure is the equilibrium price of emissions in a cap-and-trade market, or the emission tax rate that induces the required level of emission reduction. The emissions price measures the marginal cost of an additional unit of emission reduction. By itself, however, this is an incomplete proxy for the total cost to the economy of emission reduction.[40] A related metric is the Marginal Abatement Cost (MAC) curve, which exhibits the aggregate (typically economy-wide) relationship between tons of emissions abated and the marginal cost of abatement (specifically, the equilibrium price of emissions). Under simplified conditions, the area under this curve provides an estimate of total cost of abatement, but it does not capture some of the economy-wide effects associated with existing distortions.[41]

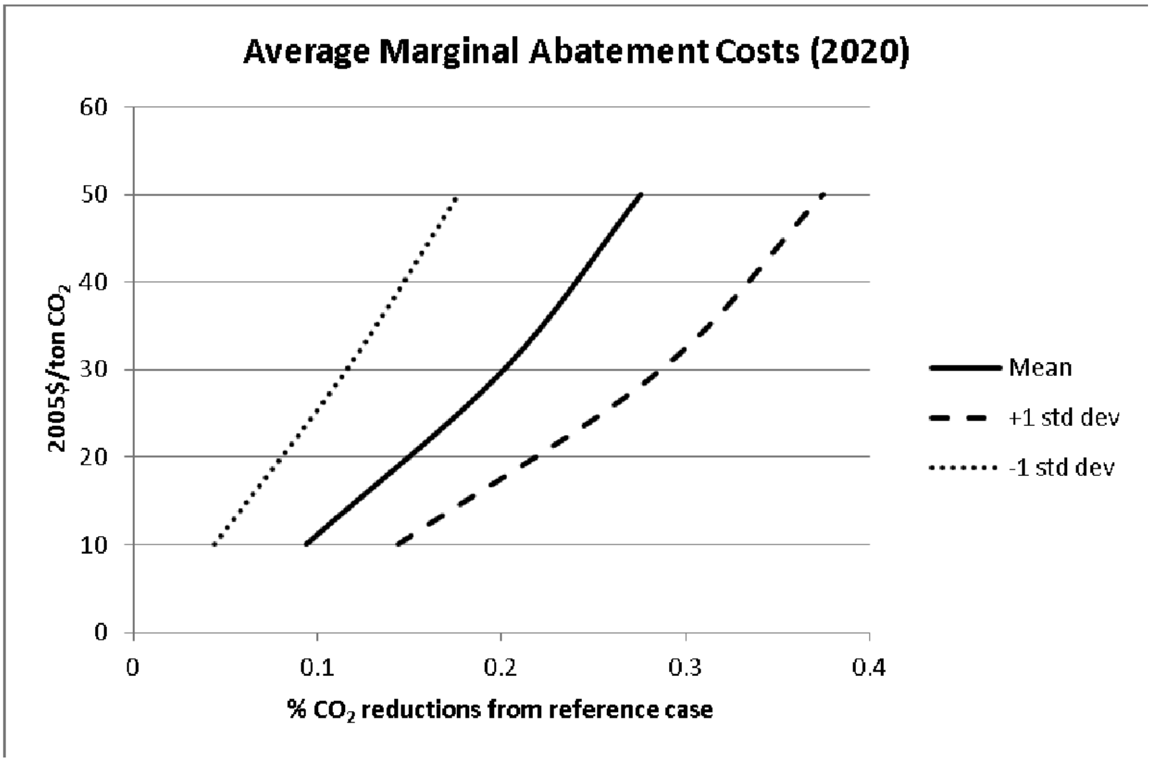
Figure 3.5 presents estimates of the expected emission reduction as a function of the price of carbon faced by global society, taken from the analysis in Chapter 6 of this volume (we have not independently evaluated the reliability of the figures). Shown are two subfigures, one for 2020 and one for 2050, with the primary difference being expected technological change.

Box 3.6 describes an alternative derivation of the marginal abatement cost curve, which has aroused some controversy.

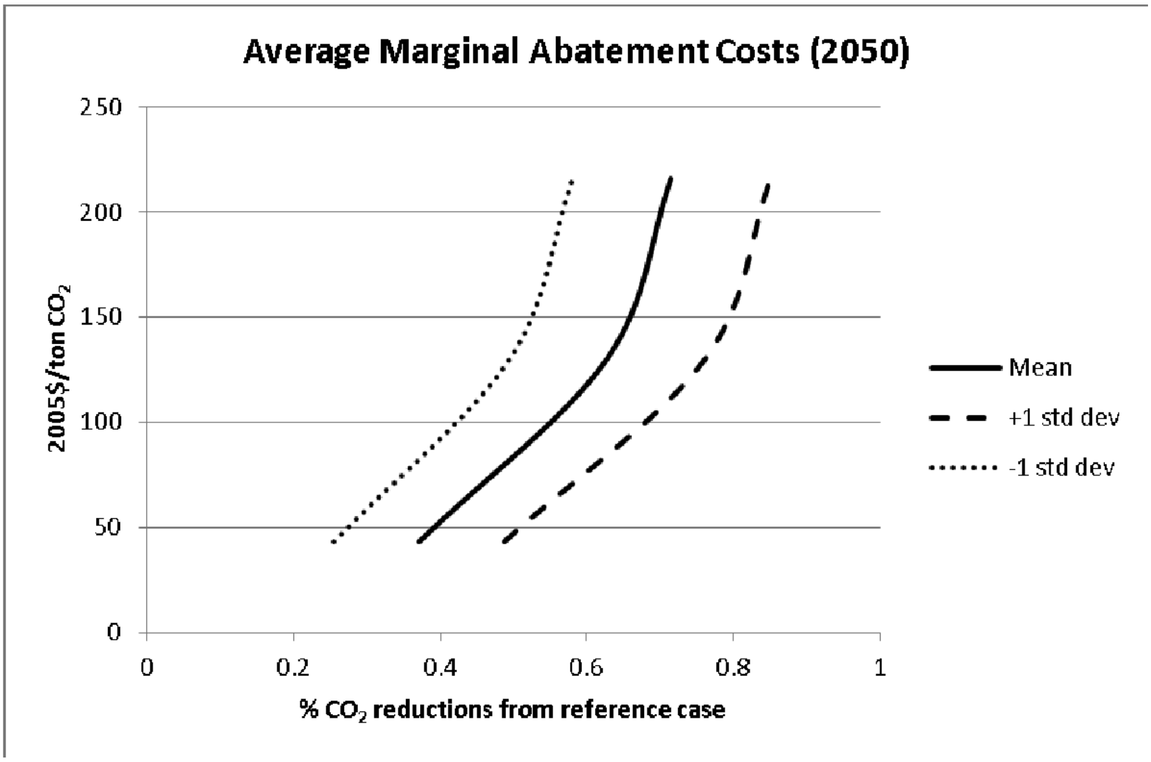
[39] While there is a growing body of evidence showing that behavioural factors have a real influence, as summarized in section 3.6.4, their potential overall impact on the cost of mitigation has not been assessed.

[40] Multiplying the tons of emissions abated by the emissions price overstates the cost of abatement; but, it does not account for other costs arising from distortions in the economy.

[41] Paltsev et al. (2007).



(a)



(b)

Figure 3.5. Marginal Abatement Cost (MAC) curves for 2020 and 2050. Note: These data are from a family of MAC curves generated by different models; for example, the mean is the mean MAC over the various models.

Box 3.6. The McKinsey Curve

Since 2007, McKinsey & Company has published several versions of a graph (globally, by region and sectors) plotting the cost of abatement against the quantity of GHG emissions abated using a variety of abatement measures, many related to raising energy efficiency, others relating to the use of renewable energy, improved land use management, and carbon capture and sequestration for coal and natural gas. These have been highly controversial representations of mitigation potential, in part because the methodology for generating the curve is proprietary and also because it has not emerged from the refereed literature (thus it is difficult to evaluate its validity). One such curve is shown the figure below, showing the cost of abatement (in US$ per ton of CO_2e) as a function of the quantity of GHGs (in $GtCO_2e$) that could be abated worldwide by 2030 compared to a projection of Business as Usual emissions.

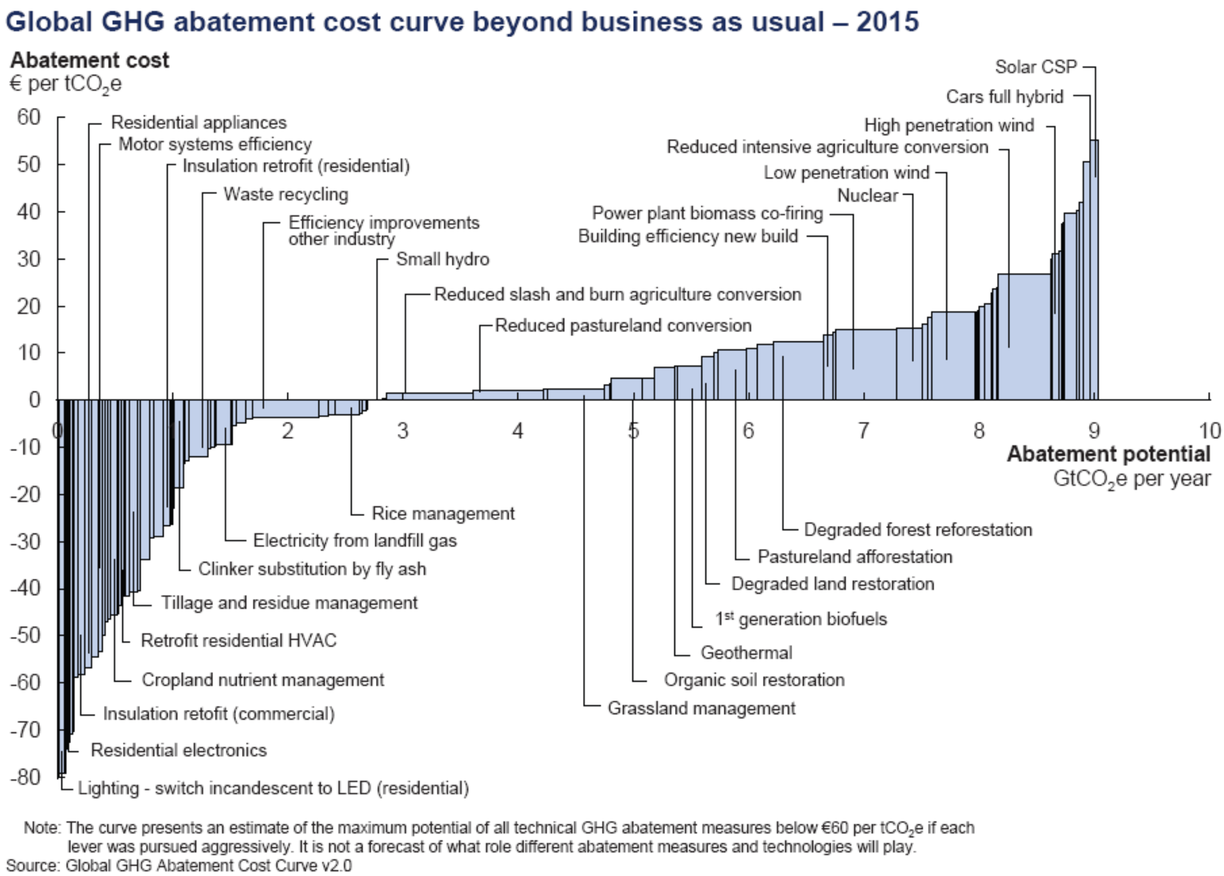


Figure 3.6. McKinsey Global GHG Abatement Cost Curve (v2.0) beyond BAU - 2015

This curve is a version of an MAC curve, although it is derived in a different manner than the MAC curves presented above in Figure 3.5. The McKinsey curve is based on a bottom-up expert assessment of the cost and emission reduction potential of each measure considered and the technological progress that can be expected between now and 2015, with the measures then arrayed from cheapest to most expensive.[42]

[42] This type of analysis was first conducted by Meier (1982) for the reduction of electricity use. The costs in each segment are an average cost; the curve is considered a marginal cost curve across alternative

The McKinsey curves have been highly controversial representations of mitigation potential, partly because of the methodology for generating the curves and partly because it is proprietary. They attracted considerable attention because it showed the potential for a substantial amount of GHG emission reduction at a *negative* cost (and such negative cost mitigation opportunities are not limited to the McKinsey curves). Those tranches of emission reduction were a free lunch. Whether that conclusion is correct has been much debated. It may be that the estimates are flawed – in the field, the savings may not be as large or the costs as low as estimated. Or indeed there may be such negative cost opportunities.[43] McKinsey's analysis ignores the distribution of costs and benefits and simply focuses on the net cost of the measures considered; if the benefits accrue to parties who do not bear the costs, this could cause an adoption failure. There may also be hidden barriers to adoption that McKinsey overlooks. Could mechanisms or business models be created that overcome the principal-agent problem or the hurdle of financing initial costs? Are there policy interventions that would make emission reduction more salient to energy users? The answers may be yes, but that goes well beyond the analysis incorporated in the McKinsey curves as presently constructed.

3.10.3 Emissions metrics

Methane and carbon dioxide are both potent greenhouse gases, with very different physical characteristics. Unit for unit, methane is a more potent greenhouse gas than carbon dioxide, yet methane has a much shorter residence time in the atmosphere. How to compare and allocate mitigation efforts among various greenhouse gases (of which there are many)?

The purpose of emission metrics is to establish an exchange rate, i.e. to assign relative values between physically and chemically different greenhouse gases (GHG) and radiative forcing agents (Fuglestvedt et al., 2003; Plattner et al., 2009). In particular, such exchange rates are required for aggregating emissions into total GHG emission inventories, or to determine the relative prices of different GHGs in the context of a multigas emission trading system. Since metrics quantify the trade-offs between different GHGs, any metric application in economic contexts explicitly or implicitly evaluates the marginal utility of emission abatement of different gases.

To be more specific, start with an overall objective of minimizing net costs (NC), defined as the sum of the net mitigation costs from emissions less the damages from climate change:

Equation 3.7.

$$\min_{e1,e2}\{NC(t)=\int_t^{\infty}\beta(t,\tau)[C(e_\tau^1)+C(e_\tau^2)-D(c_\tau)]d\tau\}$$

Where e^1 and e^2 are emissions trajectories of two different gases which contribute in a complex physical way to climate and β(t,τ) is a temporal discount factor, as discussed in section 3.4. For any solution to the above optimal control problem, the ratio of the marginal contributions of each gas to the objective at any point in time defines the appropriate exchange rate.

The problem with Eqn. 3.7 is that a great deal of information, some not readily available, is needed to completely specify the exchange rate. Furthermore, emissions may not follow an optimal trajectory. As a consequence, a number of alternative "second-best" metrics have been proposed in the literature. These metrics differ in the way that changes in physical climate parameters induced

technologies because of the ranking based on cost. This type of curve, which became widely used, was first called a conservation supply curve; for a discussion see Kesicki and Strachan (2011).

[43] For example, Anderson and Newell (2004) found that engineering cost estimates omitted certain opportunity costs, physical costs or impediments, and did not account for risks perceived by energy users. Dubin, Miedema and Chandran (1986) and Nadel and Keating (1991) found that engineering estimates of energy savings could overstate field returns, sometimes greatly; for a further discussion, see Allcott and Greenstone (2012).

by a GHG are accounted for, and in the way that impacts are aggregated over time. The literature distinguishes between *absolute metrics*, and *relative metrics* (Forster et al., 2007). *Absolute metrics* quantify the impact of a forcing agent in absolute terms, while *relative metrics* express it relative to a reference gas. Virtually all *absolute* metrics can be expressed in terms of an inter-temporal aggregation of the differential impacts induced by a GHG perturbation *I* along a reference emission pathway *r* (Kandlikar, 1996; Forster et al., 2007):

Equation

$$AM_i = \int_0 \partial I[\,\Delta C(t)]/\partial E_i \;\; W(t)\, dt$$

3.8.

$$AM_i = \int_0 \partial I[\,\Delta C(t)]/\partial E_i \;\; W(t)\, dt \qquad AM_i = \int_0 \partial I[\,\Delta C(t)]/\partial E_i \;\; W(t)\, dt$$

where the *impact function* $I(\Delta C)$ describes the impact caused by a change in the physical climate paramters ΔC. $W(t)$ specifies the temporal *weighting function*. The corresponding *relative metric value* $M_i = AM_i / AM_{CO2}$ relates the impact of 1 kg of emission *i* normalized to the one of 1 kg reference gas, usually CO_2.

The *impact function* links the metric to the change in a physical climate parameter, typically the global mean radiative forcing (*RF*) or the change in global mean temperature (ΔT). In some cases, the impact function also accounts for the rate of change of a physical climate parameter (Manne and Richels, 2001; Johansson et al., 2006). Since in general both physical climate change and climate impacts are non-linear functions of emissions, the assumptions on the reference trajectory of emissions have an important effect on metric outcomes.

The temporal *weighting function* determines how the metric aggregates impacts over time. The standard approach would be to use exponential discounting, as has been discussed earlier in this chapter. Other methods from the physical sciences have also been used (e.g., equal weight to all impacts over a finite horizon or only evaluating impacts at a specified end-point).

The prevalent metrics can be categorized according to their choice of impact and weighting function (Table 3-3). Such a categorization as introduced by Deuber et al. (2012) also serves to expose underlying explicit and implicit assumptions, and relevant normative judgements.

From an economic point of view, the first best approach is to construct climate metrics based on the marginal climate damages caused by different GHGs, thus accounting for the full causal chain of impacts. The *Global Damage Potential (GDP)* metric follows this approach by using climate damages as an impact proxy, and exponential discounting for intertemporal aggregation of impacts (Hammitt et al., 1996; Kandlikar, 1996). GDP thus assumes a unique position within the group of metrics proposed in the economic literature. By establishing the exchange ratio between GHGs based on the ratio of the future stream of discounted, marginal damages, the GDP fulfils a necessary condition for economic efficiency under a multi-gas mitigation effort. The GDP depends on the state of the background atmosphere, as well as socio-economic vulnerability. Its numerical values will therefore change over time.

In practice, the GDP is very difficult to operationalize (Tol et al., 2004; Deuber et al., 2012). Given the challenges of operationalizing GDP, an alternative (second-best) approach is to use physical metrics or economic metrics based on the cost-effectiveness rationale. Physical metrics avoid the perils of economic evaluation by choosing an impact parameter that is located further upstream in the chain of impacts. They can be considered simplified forms of the GDP in which a linear relationship between economic damage and the physical impact proxy ΔT or *RF* is assumed, and the temporal weighting function is modified (Deuber et al., 2012). In addition, many physical metrics avoid scenario uncertainty by assuming constant atmospheric background conditions. The most prominent example of a physical metric is the Global Warming Potential (GWP), which is based on *RF* as an impact proxy, and the unit-step function for intertemporal aggregation. In its version with a

100-year time horizon, the GWP is currently used for policy applications such as the Kyoto Protocol or the European Emissions Trading System.

An alternative economic metric is the *Global Cost Potential (GCP)*. It calculates the time-variant exchange ratio that ensures cost-effective multi-gas mitigation given a pre-scribed climate target (Manne and Richels, 2001). The underlying cost-effectiveness rationale can be considered a special case of the cost benefit rationale, in which damages are assumed to be zero below a threshold, and infinity above (Tol et al., 2008). Thus, the GCP can also be considered a special case of the GDP. If used with a temperature target, the GCP yields qualitatively comparable results to the GTP, which evaluates the temperature change induced at a given point in time in the future arising from a pulse emission (Shine et al., 2007). An even better agreement approximation of the GCP by a physical climate metric has been demonstrated by the *cost-effective temperature potential (CETP)*, which by construction of its temporal weighting function only considers climate impacts that occur after the climate target has been reached (Johansson, 2012). The symmetry between certain physical metrics like the GTP and its derivates on the one side, and the economic GCP on the other side arises from the fact that both approaches only consider the long-term effect of emissions, either by explicitly assuming a temporal weighting function that excludes the short and medium time-scales (as in the case of the GTP), or by assuming an impact function that is non-zero only in the distant future (as in the case of the GCP). It has given rise to the categorization of these metrics as cost-effectiveness metrics, as opposed to the cost-benefit metrics GDP and integrative physical metrics like the GWP (Tol et al., 2008).

In essence, the choice of an appropriate metric for policy applications involves a trade-off between economic efficiency and the explicit representation of relevant uncertainties on the one hand, and simplicity and transparency on the other hand (Skodvin and Fuglestvedt, 1997; Fuglestvedt et al., 2003; Plattner et al., 2009). The GDP is based on first economic principles, and thus ensures an economically efficient trade-off between different GHGs, but is subject to large value-based and scientific uncertainties. Simple physical metrics, such as the GWP, are easier to calculate and more transparent in their calculation, but are inaccurate in representing the relevant damage trade-offs between different GHGs (Fuglestvedt et al., 2003; Tol et al., 2008; Deuber et al., 2012).

The choice of metric can have strong effect on the numerical value of GHG exchange rate. This is particularly relevant for methane, which has an atmospheric lifetime that is significantly shorter than that of CO_2: a metric that emphasizes impacts occurring in the short term will result in a higher metric value for methane (Boucher, 2012), thus creating stronger emission reduction incentives on CH_4 emitting sectors such as agriculture (Reisinger et al., 2012).

A few studies have analysed the economic implications of using alternative metrics (Godal and Fuglestvedt, 2002; O'Neill, 2003; Johansson et al., 2006). These studies conclude that the cost penalty for using the standard 100-year-GWP increases the costs of achieving a prescribed climate target by less than 5% compared to the mitigation costs in a first-best economic approach. Further studies using current state-of-the-art integrated assessment models with a detailed representation of non-CO_2 emissions would help to corroborate these findings

Table 3-3: Overview and classification of different metrics from the scientific literature

Name of metric		Impact function	Atmospheric background	Temporal weighting function	Reference
GWP	Global Warming Potential (unit step)	$I \propto RF$	constant	$W(t)=\theta(H\text{-}t)/H$	IPCC (1990)
GWP-LA	Global Warming Potential (discounting)	$I \propto RF$	constant, average of future conditions	$W(t)= r\ exp(\text{-}rt)$	Lashof and Ahuja (1990)
EGWP	Economic Global Warming Potential	$I \propto$ a RF + b $\partial RF/\partial t$	constant	$W(t)= r\ exp(\text{-}rt)$	Wallis (1994)
GTP	Global Temperature Potential	$I \propto \Delta T$	exogenous scenario	$W(t) = \delta(t\text{-}t_x)$	Shine et al. (2005), Shine et al. (2007)
CETP	Cost Effective Temperature Potential	$I \propto \Delta T$	exogenous scenario	complex function of time when climate threshold is reached	Johannson (2012)
MGTP	Mean Global Temperature Potential	$I \propto \Delta T$	constant	$W(t)=\theta(H\text{-}t)/H$	Gillet and Mathews (2010)
TEMP	Temperature Proxy Index	$I \propto \Delta T$	historical scenario	$W(t)=\theta(\text{-}t)$	Tanaka et al. (2009)
GCP	Global Cost Potential	implicit: $I = \Theta_\infty\ (\Delta T\text{-}\Delta T_x)$	endogenous scenario	$W(t)= r\ exp(\text{-}rt)$	Manne and Richels (2001)
GDP	Global Damage Potential	$I \propto D(\Delta T)$	exogenous scenario	$W(t)= r\ exp(\text{-}rt)$	Kandlikar (1996), Hammit et al. (1996)

3.10.4 The Damages from Climate Change

In order to assess a proposed mitigation policy, one needs to compare an economic measure of its costs with an economic measure of its benefits. This subsection summarizes the literature that has developed on the economic value of damages from climate change and benefits from mitigation.

The projections of future changes in climate – changes in temperature and precipitation – of the sort generated by global climate models, along with projections of sea level rise, are only the starting point for an accounting of benefits. To get at how people may be affected by such changes, they have to be translated into changes in physical, biological and social systems that more directly affect human wellbeing – for example, changes in crop yield, water supply, disease incidence, species abundance, wildfire, coastal flooding, etc. Only when changes in those endpoints have been characterized can the economic valuation begin.[44] The changes that impact human wellbeing can be classified as market and non-market. The market impacts involve the same type of things as those listed earlier in connection with the costs of mitigation – changes in income, and changes in the prices, availability or quality of marketed commodities. Non-market changes are changes in the quantity or quality of things that matter to people, even though they don't obtain them through the market. There are many examples of such non-market items that people value including health, quality of life, culture, environmental quality, natural ecosystems, wildlife, etc. A given change in a physical or biological system can generate both market and non-market impacts on human wellbeing. For example, an episode of extreme heat in a rural area may cause heat stress for exposed farm labourers and dry up a wetland that serves as a refuge for migratory birds, while killing some crops and impairing the quality of others that survive. From an economic perspective, the damages would be conceptualized as a loss of income for farmers and farm workers; an increase in

[44] Some researchers adopt the convention of referring to the physical, biological and social impacts as "injuries" and the monetized value of those impacts as "damages."

prices of crops for consumers and/or a reduction in their quality; and non-market impacts including the impairment of human health and ecosystem harm.

The economic value of the resulting change in wellbeing is measured in monetary terms through the equivalent change in income using the willingness-to-pay (WTP) or willingness-to-accept compensation (WTA) measures. Although the idea of WTP as an economic measure goes back to Dupuit (1844) and Marshall (1890), the theoretical foundation for the WTP and WTA measures was clarified and the economic methods of measurement were formalized about forty years ago, first for market valuation[45] and soon thereafter for non-market valuation.[46]

The economic value of an item is not in general the same as its price.[47] Some things that people value do not have a market price. And, even if the item does have a price, the person might be willing to pay *more* than the price to obtain it; if so, this extra WTP is part of its value to the person. However, where items do have a price and can be obtained through the market, an individual's purchase behaviour reveals his WTP value for the item. This *revealed preference* is derived on the basis of both the price that he paid and also the inferred price at which he would cease to buy the commodity. The key requirement is observation of his purchases sufficient to estimate a demand function characterizing his choice behaviour. The WTP or WTA measure is derived from the estimate of the demand function.[48] With revealed preference, the analyst relies on tradeoffs observed to be occurring in economic markets. With *stated preference*, the other approach to welfare measurement, the analyst employs a survey or economic experiment in which subjects are confronted directly with a tradeoff. For example, they are asked to choose between making a payment (for example, a tax increase) and having a program undertaken that brings about the specific outcome (for example, protection of a particular ecosystem), or not making the payment and not securing that outcome. The WTP (or WTA) measure is derived from the pattern of survey responses.[49] These valuation techniques have been widely used by government agencies for administrative and legal decisions in many contexts including health, education, the arts, transportation and social policy as well as ecosystems and the environment.[50] There is also a small but growing literature in which they have been applied to the valuation of damages from climate change.[51]

It is important to note that the income equivalence measures are anthropocentric: they represent the value that a person would place on the item if he could exchange it for income. With a marketed item, if all individuals face the same price for the item and optimize their purchases, they should have the same value for the *marginal* unit of the item, since optimization entails equating the

[45] Hurwicz and Uzawa (1971), Willig (1976)

[46] Maler (1971)

[47] Price measures value only for the marginal unit purchased of a marketed commodity. For non-marginal changes in a marketed commodity, price understates value. The changes involved in climate change are generally likely to be non-marginal and, also, involve non-marketed goods.

[48] Further details can be found in Becht (1995) and the chapters by McConnell and Bockstael (2006) and Phaneuf and Smith (2006) in Maler and Vincent (2005) or in textbooks such as Champ, Boyle and Brown (2003), Haab and McConnell (2003) and Bockstael and McConnell (2007).

[49] Further details can be found in the chapter by Carson and Hanemann in Maler and Vincent (2005), or in textbooks such as Champ, Boyle and Brown (2003) and Haab and McConnell (2003).

[50] For the use of economic valuation in the UK National Ecosystem Assessment, see Bateman et al. (2011). For the US, see US EPA (2010); examples of studies by the US National Research Council using these methods include (2004) and (2010).

[51] Examples include Sohngen, Mendelsohn and Sedjo (2001), Markantonis and Bithas (2009), and Nepal, Berrens & Bohara (2007)

marginal WTP (or WTA) to the price of the marginal unit. But, for non-marketed items and for infra-marginal units of marketed items, the value would be higher than the price. Therefore, the total value placed on the item would in principle be different for different people, reflecting differences in their interests (preferences) and their circumstances, including their incomes. In particular, the total value would be expected to differ among different social groups and different countries. This is true for the valuation of impacts of climate change as it is for that of conventional marketed commodities. These differences are especially significant in the case of climate change because the impacts are felt around the world, but the body of valuation studies is small and is limited mainly to studies conducted in the US and a few other countries. Therefore in the economic models used for regional and global assessments of the damages from climate change there is a pervasive reliance on extrapolation of values from estimates of the valuation of one item by one group of people at one point in time and at one location to other locations, times and, sometimes, other items. This extrapolation, known as *benefits transfer*, is done in various ways. A common method is to extrapolate in proportion to differences in income: if one assumed that the income elasticity of WTP (or WTA) is unity, the value would scale across groups in exact proportion to differences in per capita or per household income. This approach has been criticized because it assumes that there is only a difference in income, not in preferences; the unitary value of the elasticity is just an assumption, lacking a firm empirical basis;[52] and it ignore the ethical issues associated with welfare comparisons across income groups and countries that might call for the use of equity weights.

3.10.5 Model Analyses of Damages

The first studies of the economic impact associated with a specific degree of climate change were done for the US.[53] On a global scale, the first attempt at a comprehensive estimate of the global economic impact was by Fankhauser (1994), Since then there have been about a dozen other studies of the global impact. Table 3-4, reproduced from Tol (2009), summarizes the estimates from these studies, measured with the income equivalent WTP measure and represented as a percentage reduction in GDP. Tol's summary presents the global economic loss corresponding to a specific degree of global warming, and the economic loss in the regions that are worst-off and best-off.

[52] The assumption is often justified on the basis that there is probably a unitary elasticity of demand for the environment. Even if that were true, however, the income elasticity of willingness to pay is numerically different from the income elasticity of demand (Hanemann, 1991).

[53] Nordhaus (1991), Cline (1992).

Estimates of the Welfare Impact of Climate Change

Study	*Warming (°C)*	*Impact (% of GDP)*	*Worst-off region* (% of GDP)	*Worst-off region* (Name)	*Best-off region* (% of GDP)	*Best-off region* (Name)
Nordhaus (1994a)	3.0	−1.3				
Nordhaus (1994b)	3.0	−4.8 (−30.0 to 0.0)				
Fankhauser(1995)	2.5	−1.4	−4.7	China	−0.7	Eastern Europe and the former Soviet Union
Tol (1995)	2.5	−1.9	−8.7	Africa	−0.3	Eastern Europe and the former Soviet Union
Nordhaus and Yang (1995)[a]	2.5	−1.7	−2.1	Developing countries	0.9	Former Soviet Union
Plambeck and Hope (1996)[a]	2.5	2.5 (−0.5 to −11.4)	−8.6 (−0.6 to −39.5)	Asia (w/o China)	0.0 (−0.2 to 1.5)	Eastern Europe and the former Soviet Union
Mendelsohn, Schlesinger, and Williams (2000)[a,b,c]	2.5	0.0[b] 0.1[b]	−3.6[b] −0.5[b]	Africa	4.0[b] 1.7[b]	Eastern Europe and the former Soviet Union
Nordhaus and Boyer (2000)	2.5	−1.5	−3.9	Africa	0.7	Russia
Tol (2002a; b)	1.0	2.3 (1.0)	−4.1 (2.2)	Africa	3.7 (2.2)	Western Europe
Maddison (2003)[a,d,e]	2.5	−0.1	−14.6	South America	2.5	Western Europe
Rehdanz and Maddison (2005)[a,c]	1.0	−0.4	−23.5	Sub-Saharan Africa	12.9	South Asia
Hope (2006)[a,f]	2.5	0.9 (−0.2 to 2.7)	−2.6 (−0.4 to 10.0)	Asia (w/o China)	0.3 (−2.5 to 0.5)	Eastern Europe and the former Soviet Union
Nordhaus (2006)	2.5	−0.9 (0.1)				

Note: Where available, the estimates of uncertainty are given in parentheses, either as standard deviations or as 95 percent confidence intervals.
[a] The global results were aggregated by the current author.
[b] The top estimate is for the "experimental" model; the bottom estimate for the "cross-sectional" model.
[c] Mendelsohn et al. only include market impacts.
[d] The national results were aggregated to regions by the current author for reasons of comparability.
[e] Maddison only considers market impacts on households.
[f] The numbers used by Hope (2006) are averages of previous estimates by Fankhauser and Tol (1997); Stern et al. (2006) adopt the work of Hope (2006).
(expressed as an equivalent income gain or loss in percent GDP)

Table 3-4: Estimates of the Welfare Impact of Climate Change – expressed as an equivalent income gain or loss in percent GDP. [Source: Tol (2009)]

Not all the damage estimates in Table 3-4 are associated with models that also measure the economic costs of mitigation, as discussed in section 3.9.2 . Three such models, welfare-maximization IAMs, are represented in Table 3-4. These are the DICE model (Nordhaus, 2008, 2010) and its regional cousin, RICE (Nordhaus and Boyer, 2000); the FUND model (Tol and Yohe, 2009); and the PAGE model (Hope, 2006).[54]

To explain these models, it is useful to start with an idealized conceptualization of damage estimation. Let time be denoted by the subscript t, where the units are years or groups of decades, such as decades. Let t = 0 be the present; t > 0 represents some future time, and t < 0 represents a past time, going back to t = -T. E_t is global emissions of GHGs (typically in in $GtCO_2e$) in period t. W_{kt} is a vector of climate change variables at location k in period t; let the different variables be indexed by c = 1,..,C, which are variables like temperature, precipitation, for coastal areas, mean sea level, etc. The elements of W_{kt} are derived from the trajectory of global emissions passed through a global climate model, and perhaps also downscaled to location k through a regional climate model or a statistical downscaling technique. That mapping is represented by functions $W_{ckt} = F_{ckt}(E_{-T}, E_{-T-1}, \ldots, E_0, \ldots, E_t)$. The damage measurement starts where the climate modeling leaves off, with the W_{ckt}'s, and involves two mappings. Let I_{ikt} denote the ith type of physical, biological or social impact occurring at location k in period t, and let D_{ikt} denote the monetized value of the that impact at that location and that time. There is a mapping $T_{ikt}(\cdot)$ from the W_{lt}'s to I_{ikt}. A given I_{ikt} may depend may depend on climate outcomes, c, at location k, either currently (W_{ckt}) or in the past ($W_{ck\tau}$, $\tau < t$) or at other locations (for example upslope) (W_{clt}); it may depend not on levels of climate variables but on changes ($W_{ckt} – W_{ckt-1}$), rates of change ($[W_{ckt} – W_{ckt-1}]/ W_{ckt-1}$), or cumulative changes ($W_{ckt} – W_{ckt-N}$). Secondly, there is a mapping, $V_{ikt}(\cdot)$ from the I_{ilt}'s to D_{ikt}. In this mapping, the economic damage D_{ikt} may depend not only on the impact itself, I_{ikt} , but also on related impacts in preceding periods (I_{ikt-1}) or other locations (I_{ilt}). The economic damage in period t, D_t, is the sum[55]

Equation 3.9. $$D_t = \sum_{ik} V_{ikt}[T\{ F(E_{-T},..,E_{-0},..,E_t)\}]$$

Three metrics of aggregate impact are common in the literature. One metric is total cost, expressed as an equivalent reduction in GDP and measured at a national, regional, or global scale, for a specified future year or a specified rise in global mean temperature. Thus, the damages in Table 3-5 correspond to estimates of D_t at future date (often 2100) by which time global average annual temperature will have risen 2.5°C, or whatever amount is listed in the first column of Table 3-5. The second metric is the discounted present value of the stream of present and future damages over some relevant period of time,

Equation 3.10. $$D_0 = D_0(E_{-T},..,E_{-0},..,E_t) \equiv \sum_{t\geq 0} D_t \delta_t$$

where $\delta_t = (1+r)^{-t}$ is a factor that discounts monetary values in future year t back to t = 0. The third metric is the marginal economic cost of an increase of one unit in aggregate emissions today, $\partial D_0/\partial E_0$, often known as the social cost of carbon (SCC). All three metrics can be generated with the three IAMs being considered here.

Equation 3.9 represents a full physical and economic impact assessment from the bottom up. This is a complex and multi-dimensional undertaking. A vast amount of data would be needed to construct the mappings $G_{ikt}(\cdot)$ and $H_{ikt}(\cdot)$. Rather than doing this, the IAMs use a highly simplified analysis of climate impacts. The spatial unit of analysis in DICE and PAGE is the entire world; in FUND the world is divided into 16 broad regions; RICE involves 12 regions (Nordhaus, 2010). In DICE and

[54] The most commonly reported damage estimates in the literature are drawn from these four models or their variants. Some other welfare maximization IAMs are reviewed in Ackerman et al (2009).

[55] For simplicity, we drop the subscripts associated with the mappings $G_{ikt}(\cdot)$ and $F_{ckt}(\cdot)$. The damage, D_t, is typically represented as a percentage reduction in annual GDP. In that case, the absolute amount of the damage is essentially the product of D_t and GDP.

PAGE, the climate parameter, W_{kct}, is the change in global annual mean temperature, ΔT. In FUND this is mapped into a change in regional annual mean temperature with a fixed multiplier for each region. The compound of the mappings $G_{ikt}(\cdot)$ and $H_{ikt}(\cdot)$ is replaced by a simple reduced form equation in which D_t, the percentage of GDP lost when temperature rises by ΔT, is a power function calibrated to damages estimated at some benchmark temperature change, ΔT* (recorded in the first column of Table 6.z). In PAGE, the damage function is[56]

Equation 3.11. $$Dt = a[\Delta T/\Delta T^*]b$$

so that, at the benchmark ΔT*, $D_t = a$.

Two striking features of these damage functions are the high level of spatial aggregation and a reliance on expert judgment for calibration. While clearly unavoidable, both are grounds for some concern.

The parameters used to calibrate Equation 3.9 (or 3.11) are not necessarily consensus judgments from the literature. While growing rapidly in recent years, the literature on the economic cost of climate impacts is sparse and fragmented, and until recently focused mainly on the USA and some European countries. The parameters are calibrated by the model developer based extrapolation from studies in literature to other countries and regions. DICE, FUND and PAGE draw on the same literature for calibration, much of which involves studies published prior to 2000. DICE, FUND, and mean estimates from PAGE give fairly similar conclusions about the economic damage associated with specific emissions scenarios. But DICE and FUND differ markedly in their assessments of the sectoral composition of damages. In FUND, the single largest component of the social cost of carbon is damages from energy, which account for two thirds of total, followed by water, which accounts for 1%. The damages are offset by a large gain to agriculture, which reduces the total cost by half. In DICE, there is no impact on water, almost zero impact on energy, and a small loss to agriculture; two thirds of the gross damage is attributed to catastrophic climate events rather than to market or other non-market impacts. The inconsistencies suggest that some further refinement of sectoral damage estimates may be desirable.

The spatial aggregation combined with a focus on the increase in global mean temperature as a summary statistic tend to bias the damage estimates downwards. The degree of temperature increase is different for land and ocean areas and varies by latitude; as a generalization, it is higher on land and at the latitudes where most of the world's population live, and where the studies used for calibration apply.[57] Moreover, the spatial averaging causes an understatement of damages because of the convexity of the damage function (increasing marginal damage), exploiting Jensen's inequality. Using the approximation for expected damages of

Equation 3.12. $$E\{D(\Delta T)\} = D(E\{\Delta T\}) + \sigma 2\Delta D''(E\{\Delta T\})$$

where σ^2_Δ is the spatial variance in temperature increase and $D''(\circ)$ is the second derivative of the damage function, the degree of understatement in the IAM damage functions is greater the greater

[56] Weitzman (2009) argues that the multiplicative formulation involving a product of GDP and damages is somewhat arbitrary; he shows that an additive formulation in which damages are subtracted from GDP can significantly increase the economic impact of climate damages.

[57] For example, Hayhoe et al. (2004) examine climate impacts in California for a standard GHG emission scenario, using results from the HADC3M model. The downscaling used by Hayhoe et al. (2004) shows that the corresponding statewide average annual temperature increase in California in 2100 is 3.3 oC, the statewide summertime temperature increase (when most of the adverse impacts are likely to occur) is 4.6 oC, and in the Central Valley (where most of the agriculture occurs) and Southern California (where a majority of the population live) the increase in summertime temperature approaches 5 oC. Representing this as an increase of ΔT = 2oC or 2.4 oC is likely to understate the damages.

the degree of spatial aggregation (leading to a higher σ^2_Δ) and the greater the curvature of the damage function.

Some recent issues in discussions of these IAMs are (1) their treatment of large increases in global temperature and abrupt climate change, and (2) their treatment of uncertainty regarding climate impacts. The IAMs are calibrated to increases in global temperature of 2 or 3°C. Recently, however, there has been increased attention to the possibility of tipping points[58] and much larger increases in global temperature, possibly as large as 10°C. From the existing physical and economic impact assessments, there is no basis yet for calibrating damage functions to this higher temperature range. Since Weitzman (2007, 2009, 2011) drew attention to the possibility of a "fat" right tail in the probability distributions for temperature increase and damages, several studies have modified DICE and PAGE to allow the damage functions to be more sensitive to large temperature increases, and have found that this significantly raises the estimate of damage.[59]

There is much uncertainty embedded in the IAMs, including the climate sensitivity (the long-run increase in global average temperature arising from a doubling of atmospheric CO2 concentration), the shape and parameters of the damage function given an increase in global average temperature, the background rate of growth in consumption that would occur in the absence of damage from temperature increase and/or investment in abatement, the cost of abatement, and other model parameters such as the rate of time preference or the degree of risk aversion. The effect of such uncertainties has been investigated mainly by running IAMs for different draws of parameter values and then averaging the results.[60] This approach implicitly assumes that there is only uncertainty about the state of the world before the model is initialized; once the model is endowed with a given set of parameter values it is solved without uncertainty. An alternative approach solves the IAM with the uncertainty in place; this approach, which was adopted by Kolstad (1996), Kelly and Kolstad (1999), Keller, Bolker and Bradford (2004) and is computationally more demanding.

3.11 Behavioural economics and culture

3.11.1 Behavioural Economics and the Cost of Emission Reduction

This section summarizes the positive dimensions of behavioural economics related to climate change policy, as well as the policy implications thereof. We focus on systematic deviations from the neoclassical economic model, which assumes that preferences are complete, consistent, and transitive, humans are not altruistic, and humans have unbounded computational capacity, unbounded attention, and rational expectations. There are many documented systematic deviations from the neoclassical model, but here we focus on the several that we view to be most relevant to climate change.[61]

3.11.1.1 Consumer Undervaluation of Energy Costs

There is some possibility that consumers "undervalue" energy costs when they purchase energy-using durables such as lighting, air conditioners, and cars or make other investment decisions related to energy use. By "undervalue," we specifically mean that consumers' decisions systematically fail to maximize "experienced" utility, and this misoptimization reduces demand for energy efficiency.

[58] Lenton et al. (2008).

[59] Ackerman et al. (2009).

[60] Examples include Hope (2006), Nordhaus (2008), Dietz (2009), Ackerman et al (2009), Greenstone et al (forthcoming).

[61] See also American Psychological Association (2010), Brekke and Johansson-Stenman (2008), Gowdy (2008), (2000) and Rachlinski (2000).

Three potential mechanisms of undervaluation may be most important. First, when considering a choice with multiple attributes, there is evidence that consumers are inattentive to "add-on costs" or ancillary attributes such as shipping and handling charges and sales taxes (Hossain and Morgan, 2006; Chetty et al., 2009). It is possible that energy efficiency is a similar type of ancillary product attribute and is thus less salient at the time of purchase. Second, there is significant evidence across many contexts that humans are present biased (DellaVigna, 2009). If energy costs are paid in the future, this would also lead consumers to be less energy efficient than their long-run Pareto optimum. Third, people's beliefs about the implications of different choices may be systematically biased (McKenzie et al., 2007; Jensen, 2010; Bollinger et al., 2011; Kling et al., 2012). Attari et al. (2010) show that people systematically underestimate the energy savings from a set of household energy conservation activities, and Allcott (2011) shows that the average consumer either correctly estimates or slightly systematically underestimates the financial savings from higher-fuel economy vehicles.

Each of these three mechanisms of undervaluation appears plausible based on results from other contexts. However, there is limited rigorous evidence in the specific context of energy demand, because the present discounted value of energy costs can be difficult to measure in some contexts and because there are often unobserved features of choice situations that make it difficult to prove that consumers are misoptimizing (Allcott and Greenstone, 2012).

There are three implications for energy policy if the average consumer who is marginal to a policy does in fact undervalue energy costs (WORKING PAPER: (Allcott et al., 2012). First, there is an "internality dividend" from carbon taxes (or other policies that internalize the carbon externality into energy prices): whereas carbon taxes are often thought to reduce economic growth in the service of reducing carbon emissions, a carbon tax can actually increase consumer welfare when consumers undervalue energy costs. The intuition is that undervaluation is a pre-existing distortion that reduces demand for energy efficiency below consumers' private optima, and increasing carbon taxes helps to correct this distortion. 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 affect consumers that undervalue energy costs the most. This fact 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 impinge 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 other programs that provide information about and draw attention to energy use of energy-using durable goods in retail stores.

3.11.1.2 Non-Price Interventions to Reduce Energy Demand

Aside from carbon taxes and other policies that affect relative prices, other non-price interventions can reduce energy demand and therefore reduce carbon emissions. Such interventions include working with consumers to set energy use goals, provide commitment devices, or draw attention to energy use (Stern, 1992; Abrahamse et al., 2005). They also include feedback on historical energy consumption (Fischer, 2008) and information on how one's energy use compares to a social norm (Allcott, 2011).[62] In some cases, non-price energy conservation programs have low costs to the program operator, and it is therefore sometimes argued that they are potential substitutes if carbon taxes are not politically feasible.

[62] 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 section.

One issue is whether such interventions are appropriate substitutes for carbon taxes. One reason is that these interventions may have unaccounted costs that reduce the true welfare gains: for example, consumer expenditures on energy efficient products may be unobserved, as well as the time spent to turn lights off or guilt from being informed that they waste energy.

Research in other domains (e.g., Bertrand et al., 2010) has shown that people's choices are sometimes not consistent, but instead are malleable by "ancillary conditions," which are non-informational factors that do not affect experienced utility. In the context of energy efficiency, this could imply that energy demand could be reduced at zero welfare cost through by advertising campaigns aimed at changing consumer preferences. Economic science has little to say about the ethical and political issues surrounding publicly-funded persuasion and marketing programs.

3.11.1.3 Altruistic Reductions of Carbon Emissions

In many contexts, it is clear that people are altruistic: they are willing to reduce their own welfare to increase the welfare of others. For example, in laboratory "dictator games," people voluntarily give money to others (Forsythe et al., 1994), and charitable donations in the United States amount to more than two percent of gross domestic product (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), and in the U.S., where the data are most easily available, 1.1 million households voluntarily pay extra for lower-carbon electricity (Energy Information Administration, 2010).

Pre-existing altruistic voluntary carbon emission reductions could moderate the effects of a new carbon tax on energy demand. The reason is that when monetary incentives are introduced, this 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 financially-motivated carbon emission reductions. While this effect may not weaken the welfare argument for a carbon tax, it does reduce the predicted elasticity of carbon emissions to a carbon tax relative to the neoclassical model.

3.11.1.4 Human ability to understand climate change

So far, this discussion has covered deviations from the neoclassical model that affect energy demand. There are also deviations from the neoclassical model that affect the process of making climate policy by affecting policymakers' and voters' perceptions of the costs and benefits of policy action. Here, we highlight several.

First, when making decisions, people tend to overweight outcomes that are low-probability or especially "available" or salient (Kahneman and Tversky, 1974, 1979). If some of the potential costs of climate change such as natural disasters are low-probability in any particular location and are also highly salient, this may make policymakers and voters' more receptive to climate policy.

Second, people are more averse to losses than they are interested in gains relative to a reference point (Kahneman and Tversky, 1979). To the extent that climate change involves a loss of existing environmental amenities, this increases the perceived costs of climate change relative to the neoclassical model. On the other hand, if the costs of climate change abatement are framed as reductions relative to a reference rate of future economic growth, this increases the perceived costs of climate change abatement. While these factors are well understood in theory, and there is empirical evidence on the magnitudes in other contexts, it is not clear how empirically-relevant they are for climate-related decision-making.

Finally, the neoclassical model typically assumes that people have rational expectations about uncertain parameters. In the context of climate change, this would mean that while some people might understate the risks, other people might overstate the risks, but on average expectations would correspond to true values. In some parts of the world, survey evidence shows that the public's beliefs about climate change do not correspond with scientific assessments. For example, 15-20 percent of Americans do not believe that global average temperatures are rising, and only 41 percent of Americans believe that most scientists think that global warming is happening (Leiserowitz et al., 2011).

3.11.2 Social and cultural issues

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

In developed and developing countries, some governments, social organizations and individuals have tried to change cultural attitudes towards emissions, energy use, and in fact the very way in which life is conducted. In some countries, this has been modified by experiences with indigenous people. In fact, some have argued that the bio-cultural heritage represented in indigenous peoples of the world is a resource that should be valued and preserved, as it constitutes an irreplaceable bundle of teachings on the practices of mitigation and sustainability (Wallerstein, 1998). In some cases, customary local strategies have morphed into national policies, as is the case with the concepts of *Buen Vivir* and *Gross National Happiness*. In rich countries, and elsewhere in social groups with high levels of environmental awareness, interest in sustainability has given rise to cultural movements promoting significant changes in modes of thought, production, and consumption, giving them new meaning. Some have suggested this requires fostering *social capital* and *gender equality* as foundations for the construction of a sustainable society.

3.11.2.1 Buen Vivir

Buen Vivir is a concept that fosters a particular attitude towards nature, where all living beings are seen as integral (Choquehuanca, 2010). This set of thoughts and attitudes are hypothesized to replace the human centeredness relationship with nature. It is grounded in Andean indigenous culture; in Ecuador (in the Quechuan language) it is termed *Sumak kawsay,* and in Bolivia, *Qamaña,* (Gudynas, 2011). Buen Vivir is an alternative to the Western notion of welfare (based the acquisition of materials goods, individualism, and competition), as it prioritizes another set of values, such as "traditional knowledge, social and cultural recognition, and ethical – even spiritual - codes of conduct in the nature/society relation, human values, and vision of the future" (Acosta, 2008).

What distinguishes Buen Vivir from just another theory of alternative lifestyles is that is has been incorporated into the constitutions of Bolivia and Ecuador (see Box 3.7.). One of the great challenges of Buen Vivir is how to develop concrete, viable and effective strategies and actions that are different from conventional practices (Gudynas, 2011). Theoretical debates on Buen Vivir recognize that these alternative world views are not unique to the Andean indigenous communities; in fact, they occur in a variety of cultures both in Latin America and elsewhere. It is a concept that accepts and values cultural diversity, so that there are *buenos vivires* ("good livings") in different parts of society (Gudynas, 2011). Such *good livings* carry a novel world-view, promoted by social movements, academics and non-governmental organizations in various countries around the world; for some authors, these views have global validity (Walsh, 2010). Whether such an approach has any effect on GHG emissions without reducing quality of life is unclear.

Box 3.7. Excerpts from the Constitution of Bolivia (25/01/2009)

FIRST PART. TITLE 1. SECOND CHAPTER. **Article 8. I.** The State assumes and promotes as ethical-moral principles of the plural society: […] *suma qamaña* (good living), *ñandereko* (harmonious life), *teko kavi* (good life), *ivi maraei* (land without evil) and *qhapaj ñan* (noble path or life).

II. The State is based on the principles of unity, equity, inclusion, dignity, freedom, solidarity, reciprocity, respect, complimentarily, harmony, truth, balance, equity of opportunities, social and gender equity in participation, common welfare, responsibility, social justice, distribution and redistribution of social goods, to live well.

FOURTH PART. TITLE 1: CHAPTER ONE. Article 306. I. The Bolivian economic model is plural and orientated to improve the quality of life and the good living of all the Bolivians.
III. …the social and community economy will compliment the individual interest with the common good living.
Article 313. To eliminate the poverty and the social and economic discrimination, to achieve the goal of good living in its multiple dimensions, the Bolivian economic organization establishes the following goals…

Source: http://www.oocities.org/cpbolivia/texto2.htm

3.11.2.2 Gross National Happiness

Gross National Happiness (GNH) is a concept formulated by the Kingdom of Bhutan in order to plan and evaluate national development and the welfare of the country´s population. The related GNH Index is seen as an instrument of public policy that measures the progress of the Kingdom based on nine key domains (and 72 core indicators): ecology, living standards, health, education, culture, community vitality, time use, good governance, and psychological wellbeing (Royal Government of the Kingdom of Bhutan, 2012). GNH is both a critique and an alternative to the Western development model, as it eschews GDP and sees economic growth not as an end, but a means (one among many) of increasing human happiness. The GNH concept was proposed by the fourth King of Bhutan in 1980, in an attempt to see that the country´s development and modernization policies were in accord with its culture, institutions, and values. In 2008 GNH ceased to be a philosophy of governance and became a constitutional mandate, (see Box 3.8), which is meant to be put into practice by greater efforts in social infrastructure (access to health, education, clean water, and electrical power), while seeking to maintain a balance between economic growth, environmental protection, and the preservation of Bhutanese culture and traditions.

GNH differs somewhat from the Western notion of welfare insofar as its public policy objective is the attainment of a happy population, referred to by the concept of *sukha* –the human flourishing that arises from mental balance and insight into the nature of reality, rather than a fleeting emotion or mood aroused by sensory and conceptual stimuli (Ekman et al., 2005). In this context, happiness does not derive from external factors (individual recognition, material possessions, power and competition), which are the basis of the mainstream Western conception of welfare (Easterlin, 1995), but come from internal factors, such as emotions and feelings, and the prioritizing of the ability to live in harmony with nature, community, and spiritual values.

Box 3.8. Excerpts from the Constitution of the Kingdom of Bhutan (18/07/2008)

Article 9. PRINCIPLES OF STATE POLICY
2. The State shall strive to promote those conditions that will enable the pursuit of **Gross National Happiness.**

Article 5. ENVIRONMENT.

1. Every Bhutanese is a trustee of the Kingdom's natural resources and environment for the benefit of the present and future generations and it is the fundamental duty of every citizen to contribute to the protection of the natural environment, conservation of the rich biodiversity of Bhutan and prevention of all forms of ecological degradation including noise, visual and physical pollution through the adoption and support of environment friendly practices and policies.

2. The Royal Government shall:

(a) Protect, conserve and improve the pristine environment and safeguard the biodiversity of the country;

(b) Prevent pollution and ecological degradation;

(c) Secure ecologically balanced sustainable development while promoting justifiable economic and social development; and

(d) Ensure a safe and healthy environment.

3. The Government shall ensure that, in order to conserve the country's natural resources and to prevent degradation of the ecosystem, a minimum of sixty percent of Bhutan's total land shall be maintained under forest cover for all time.

4. Parliament may enact environmental legislation to ensure sustainable use of natural resources and maintain intergenerational equity and reaffirm the sovereign rights of the State over its own biological resources.

5. Parliament may, by law, declare any part of the country to be a National Park, Wildlife Reserve, Nature Reserve, Protected Forest, Biosphere Reserve, Critical Watershed and such other categories meriting protection.

Source: http://www.constitution.bt/TsaThrim%20Eng%20(A5).pdf

3.11.2.3 Indigenous peoples, gender, and social capital

Buen Vivir and GNH are examples of types of mitigation efforts that focus on traditional societies for their adaptive capacity and resilience (Moller et al., 2004). This has led to a re-evaluation of local knowledge and lifestyles of indigenous peoples (Berkes, 1999), as well as raised the possibility of implementing some of their cultural principles in climate change mitigation actions as alternatives to traditional development concepts and pathways.

It has been suggested that as 300 million indigenous people live in 75 of the 184 countries of the world, inhabiting less disturbed zones of the principle biomes of the earth (Toledo and Barrera-Bassols, 2008). Their knowledge and productive activities are linked to ecosystems, from which they are able to satisfy almost all of their needs. In many cases, they practice small-scale, labour-intensive and low energy rural production. They share a strong geographic identity, rooted in a substantial material and spiritual relationship with their land (Boutrais, 2005). They manage their resources through communal rights and reach high, levels of productivity per area unit (Garrabou Segura and Gonzalez de Molina, 2010). They are generally integrated into and sometimes marginalized by dominant societies, but they have reproduced and safeguarded their culture (to various degrees) due to the frequent isolation of their communities. Owing to their location, wealth and common culture of respect towards nature, indigenous peoples live in areas that support high levels of biodiversity (Gadgil et al., 1993). The bio-cultural diversity of traditional societies constitutes a vast repository of alternatives for monitoring at a local scale, and for innovation in facing the consequences of climate change, especially food security, desertification, declining biodiversity, and scarcity (Lykke et al., 2004; Barkin et al., 2009).

Other than indigenous peoples, women are a sector of society whose mitigation capacity has not been singled out until recent years. Since the mid-1980s, several studies have shown that the relation between communities and the environment is not gender-neutral (Dankelman, 2002).

Looking at the effects of climate change from a gender perspective means analyzing how the social construction of gender relates to the operation of the economy, politics, daily life, the environment, migration, and people´s subjectivity, in order to find the means to pose a new balance in terms of access, use, control, and benefits of all types of resources (Agostino and Lizarde, 2012). The investigation of cumulative vulnerability implies the application of the gender approach at various levels: as a category of analysis, a methodological tool (allowing the visualization of aspects of reality that are often invisible), and through political action (promoting gender equality). It is unclear how effective a gender approach to mitigation will be.

Lastly, the concept of Social Capital (SC) refers to relationships that promote social collaboration and collective action. SC is composed of a variety of elements that facilitate the development of social action (and actors) within various social structures (Coleman, 1988), and emphasizes the positive aspects of sociability, highlighting the powerful influence of non-economic factors. According to Noguera and Garcia (2008), the elements that define social capital are:

- Social networks and norms of reciprocity with temporal and spatial variability (Helliwell and Putnam, 2004).
- Norms and networks that enable individuals to undertake collective action (Woolcock and Narayan, 2000).
- The sum of all the resources of each individual or social group in relation to their position in the social structure and their way of establishing social relationships (Adler and Kwon, 2002).
- Systems of interpersonal networks.

SC is a means for people to interact in their communities based on associative networks of individuals and groups (Bourdieu, 1980), Solidarity is therefore a key component of SC, as it strengthens social networks around common interests that are proactively addressed (Portes, 1998). SC theories identify the existence of three types of relations: bonding, bridging, and linking. Each involves different levels (basic, intermediate, and high reciprocally) of access to resources and assets, depending on the type of associative organization that is present in a given community (Bebbington, 2005).

There is significant feedback between SC, human capital, and social development, because all are ways of empowering communities around decision-making and organized collective action. This is particularly important in the context of risk and social vulnerability, which increase with climate change, since the strengthening of SC causes increased community resilience. This mutual reinforcement can materialize itself in areas such as improving the management and community use of natural resources, negotiating conflicts over their use, and implementing mitigating actions agreed upon by the community (e.g. classification and disposal of waste, recycling and reusing, ecological legislation of community territory, and strategies for sustainable production and consumption, etc.) (Adger, 2003).

Pretty and Ward (2001) believe that the development of SC goes through three stages of maturity: the first associative impulse is stimulated by an external threat and depends on the intervention of external agents (reaction-dependence); this is followed by a period of internal consolidation that begins to disengage from external support (awakening-independence); and lastly the group becomes independent and its SC is expanded (awareness-independence). The ability to move through these stages depends on several factors: the perspectives of the actors in the group, internal norms and confidence in them, links and external networks, prevailing equality and inequality, and the longevity of the group.

3.11.3 Institutions for collective social action

People's actions and reactions have a strong connection with climate change, because they both contribute to the problem and can facilitate its mitigation. However, studies about perception (O'Connor et al., 1999) demonstrate that the general public is unaware of the role that individuals and society play in both phenomena. Collective action against climate change recognizes that the success of policies, strategies, and climate action plans actually relies on the degree of involvement of social agents. It has been suggested that this implies the importance of reinforcing environmental education programmes and public participation in the processes of mitigation.

Societies react collectively when they are faced with the experience of significant events, if there are structures that can give impetus to action, and if applicable solutions are available for problems that require change (Kates, 2007). Collective action to mitigate climate change would involve public policies, public institutions and organized social movements that can promote diffusion of knowledge about collective and individual responsibilities that contribute to the problem, and about the means for social involvement in its mitigation.

Certainly climate change has been well publicized in the media, but knowledge of the cause and effect of the phenomenon is variable among the public, both in developed and in developing countries; erroneous ideas persist even among well-informed people. This situation makes it difficult to be clear about collective responsibilities, which in turn is an obstacle to establishing solutions, and reduces the effectiveness of strategies for mitigation (Leiserowitz, 2006). A partial solution may be to reinforce and broaden educational strategies for disseminating scientific information, as well as its practical implications, in a way that is understandable to diverse groups in a population, with respect to age, level of schooling, activities, lifestyles, and culture (González Gaudiano and Meira Cartea, 2009). The challenge for an educational program in mitigating climate change is to construct a local and individual social representation of a problem that is global and collective. Collective action is reinforced when social actors understand they can take an active part in creating local solutions for a global problem that directly concerns them.

3.12 Technological change

Meeting aggressive emission reduction targets will be difficult without major changes in the way energy is produced and consumed. Given the current status of alternative technologies, making such changes will be costly. However, technology improvements are likely to occur, leading to lower costs. Understanding the potential for technological change requires an understanding of the process through which these changes occur. This section reviews the theories used to study environmentally-oriented technological change, along with highlighting some of the key lessons from this literature. All private sector innovation suffers from market failures. These market failures are even more acute in the case of climate change, as environmental market failures compound the problem. Thus, policy can play a key role in shaping both the direction and magnitude of climate-friendly technological change. In turn, these policy-induced innovations will lower the cost of reducing carbon emissions.

3.12.1 Market Provision of TC

Technological change includes three stages: invention (creation of an idea), innovation (commercialization of an idea), and diffusion (adoption of the newly created product). At all three stages of technological change, market forces provide insufficient incentives for investment in either the development or the diffusion of environmentally friendly technologies. Most important is the problem of environmental externalities. Because pollution is not priced by the market, firms and consumers have little incentive to reduce emissions without policy intervention. Thus, without appropriate policy interventions, the market for technologies that reduce emissions will be limited, reducing incentives to develop such technologies. In addition, new knowledge created through innovation is a public good (see, for example, Geroski, 1995). Once new ideas become public, they inspire additional innovations, or even to copies of the current innovations, for which the original inventor is not compensated.[63] These knowledge spillovers provide benefit to the public as a whole, but not to the innovator.

There are other market failures relating to technological advance that are logically and empirically distinct from the environmental externality addressed by carbon-price policy. First and foremost, creators of new knowledge, new products, or new ways of doing things do not reap all of the social returns to these creations, because others can copy and build on them. This "appropriability problem" corresponds to a positive externality that leads to under-investment in technology creation, in the same way that the negative environmental externality leads to over-use of the environment. The positive externality is largest for creations that transform or launch an entire new technology trajectory, along which many parties will earn rewards that are in part dependent on the fundamental development, but will not typically share those rewards.[64] Thus the kind of radical transformative technological change that some seek will be underprovided by the marketplace, even in the presence of optimal carbon-price policy.

There is a second potential positive externality associated with technological change that is less-widely discussed and somewhat more controversial as to its theoretical and empirical significance. There is a large empirical literature on learning-curve effects, whereby the unit cost of production for a good or component falls with its cumulative industry production. One interpretation of this empirical regularity is that there is a base of knowledge about production methods that grows through the process of production itself (Thompson, 2010). Due to the appropriability problem, the benefits of knowledge created by first movers has public good properties, including the difficultly of excluding parties from its use that may not have contributed to its generation. Those who produce early versions of a technology create a benefit, in terms of knowledge about the production process itself, that they may not be able to capture if for some reason they are displaced from the market and others come later to dominate production, benefitting from reduced costs based on knowledge produced through early production. At the same time, first-movers may generate advantages from lead-time that prevent competitors from catching up (Levin et al., 1987).

Investments in the development of new technology frequently struggle against imperfections in the market for capital. In particular, information about the potential of a new technology will always be held asymmetrically, making parties that invest in others' efforts at technology development subject to the problems of adverse selection ("lemons") and the winner's curse. These problems raise the cost of capital for financing technology development, and in some cases may make it impossible to secure financing for projects that have a positive expected present value at the appropriate discount rate (Hall and Lerner, 2010). This may be particularly acute for developing countries.

Finally, evolutionary models of technological change emphasize the path dependence of technological progress, and the importance of specific transformative events in generating or diverting technological trajectories . These transformative events may be exogenous or endogenous, but even if endogenous, they are unlikely to respond to economic incentives in any

[63] Intellectual property rights, such as patents, are designed to protect inventors from such copies. However, their effectiveness varies depending on the ease with which inventors "invent around" the patent by making minor modifications to an invention. See, for example, Levin et al. (1987).

[64] Indeed, 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 important existing technology may be able to take the entire market away from the incumbent, earning thereby profits that exceed the incremental value of the improvement.

kind of smooth or predictable way. This suggests that carbon-price policy alone is unlikely to bring such transformative events forth, certainly not in any way that can claim to be efficient.

These theoretical arguments for under-investment in technological change are generally confirmed by empirical research demonstrating that social rates of return to research and development are not only high, but that they are higher than the private rate of return. Probably the most frequently cited study is that of Mansfield and his students, who found for 17 important manufacturing innovations that the median private rate of return was 25 percent, while the median social rate of return was 56 percent (Mansfield et al., 1977). Such case-study analyses suffer from the possibility of selection bias. A survey by Griliches (1992) of econometric analyses found "surprisingly uniform" results regarding rates of return: estimates of the private rate of return are generally in the range of 15-30%, with an excess of social returns over the private rate of 50 to 100% of the private rate. Griliches concludes "R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates" (Griliches, 1992, p. 24).

3.12.2 Rate and direction of TC

Studies on the effect of policy or prices on innovation draw their motivation from the notion of induced innovation (Hicks, 1932; Binswanger and Ruttan, 1978; Acemoglu, 2002), which recognizes that R&D is a profit-motivated investment activity and that the direction of innovation responds positively in the direction of increased relative prices.[65] Empirical studies on the effect of policy and prices on environmental innovation support the induced innovation hypothesis and provide evidence of magnitude of these effects.

Initial evidence of induced technological change focused on the links between energy prices and innovation. Newell et al. (1999) examine the extent to which the energy efficiency of home appliances available for sale changed in response to energy prices between 1958 and 1993. They find that technological change in air conditioners was biased against energy efficiency in the 1960s (when real energy prices were falling), but that this bias was reversed after the two energy shocks of the 1970s. Suggesting the role that policy-induced technological change may play as climate policy moves forward, these researchers find that energy efficiency in 1993 would have been approximately one-quarter to one-half lower in air conditioners and gas water heaters had energy prices stayed at their (pre-energy shock) 1973 levels, rather than following their historical path.

Both Newell et al. (1999) and Popp (2002) also consider the timing of innovation. Innovation responds quickly to price changes. Newell et al. (1999) find that most of the response to energy price changes came within five years of those changes. Popp (2002) finds that the mean lag response time between energy prices and patenting activity is 3.71 years and that the median lag is 4.86 years. Thus, similar to Newell et al.'s findings, Popp (2002) shows that more than one-half of the full effect of an energy price increase on patenting is experienced after just five years.

Policy also plays an important role inducing innovation. Johnstone et al. (2010) find that patenting activity for renewable energy technologies, measured by applications for renewable energy patents submitted to the European Patent Office, has increased dramatically in recent years as both national policies and international efforts to combat climate change begin to provide incentives for innovation. Recent evidence also suggests that international environmental agreements provide important policy signals that both induce innovation (Dekker et al., 2012) and diffusion (Popp et al., 2011).

Dechezleprêtre *et al*. (2011) examine climate-friendly innovation using patent data from 1978-2005 for 76 countries. They consider a broad range of technologies, including renewable energy

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

technologies, carbon capture and storage, and energy efficiency technologies for buildings, lighting, and cement manufacture. As with R&D overall, most climate-friendly innovation occurs in developed countries.[66] In fact, the US, Japan, and Germany together account for two-thirds of the innovations in their sample. Reflecting the role and impact of policy, innovation increases after the Kyoto Protocol in all Annex I countries except the US, which had not ratified Kyoto.

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

There is an extensive literature using experience curves to estimate the rates of cost decreases in energy technology. In economics, this concept is often described as learning-by-doing (LBD) – the decrease in costs to manufacturers as a function of cumulative output – or "learning-by-using" – the decrease in costs (and/or increase in benefits) to consumers as a function of the use of a technology (Wright, 1936; Arrow, 1962; Rosenberg, 1982).

While learning curves are relatively easy to incorporate into most integrated assessment models of climate, there are limitations to the application of LBD as a model of technological change. Benkard (2000) raises the possibility of forgetting, as well as learning, being important. Ferioli et al. (2009) discuss limitations of learning curves for energy policy. Learning curves ignore potential physical constraints. For example, while costs may initially fall as cumulative output expands, if renewable energy is scaled up by an order of magnitude or more, the use of sub-optimal locations would increase costs. They 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. So they suggest caution when extrapolating cost savings from learning curves to long time frames or large capacity expansions.

An additional difficulty in extracting lessons from learning curves is that these studies address correlations between energy technology use and costs, not causation. This is important, as the role of learning from experience versus R&D determines the optimal timing of policy. Hendry and Harborne (2011) provide examples of how experience and R&D interacted in the development of wind technology.

To further address the problems associated with estimating and interpreting learning curves, Nemet (2006) uses simulation techniques to decompose cost reductions for PV cells into seven categories. Plant size (e.g. returns to scale), efficiency improvements, and lower silicon costs explain the majority of cost reductions. Notably, most of the major improvements in efficiency come from universities, where traditional learning by doing through production experience would not be a factor. Learning from experience (e.g. through increased yield of PV cells) plays a much smaller role, accounting for just 10 percent of the cost decreases in Nemet's sample.

3.12.4 Endogenous vs Exogenous growth

Within climate policy models, technological change is either treated as exogenous or endogenous.[67] Exogenous technological change is assumed to progress at a steady rate over time, independent of changes in market incentives. One drawback of exogenous technological change is that it ignores potential feedbacks between climate policy and the development of new technologies. Models with endogenous technological change address this limitation. Endogenous technological change models relate technological improvements in the energy sector to changes in energy prices and policy.

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[66] In 2007, global R&D expenditures were an estimated $1.107 trillion, with OECD nations accounting for 80 percent, and the United States and Japan together accounting for 46 percent (National Science Board, 2010).

[67] Köhler *et al*. (2006), Gillingham, Newell, and Pizer (2008) and Popp, Newell, and Jaffe (2010) provide reviews of the literature on technological change in climate models. This section draws heavily on the material in Popp, Newell, and Jaffe (2010).

These models all demonstrate that ignoring induced innovation overstates the costs of climate control.

The pioneering macroeconomic contribution in the economics of climate change was made by Nordhaus (1977, 1994a), who develops a dynamic integrated model of climate change and the economy (the DICE model), which extends the neoclassical growth model of Ramsey (1928) with equations representing emissions, climate change and climate damage. In this framework, a consumption good is produced using capital and labour, and the productivity of these factors depends both upon a knowledge parameter that grows exogenously over time, and upon environmental quality.

Technological change in most implementations of DICE is exogenous (as in the classic Solow (1956) model of growth). Efforts to endogenize technological change have been difficult, in large part because market-based R&D is not first best – spillovers from R&D are not taken into account when deciding how much R&D to undertake. More recently, Nordhaus (2002) simulates a variant of the DICE model –the so-called R&DICE model- where again firms can either substitute capital and labour for carbon energy or invest in innovation aimed at developing new products and processes that are less carbon-intensive (but cannot do both). Nordhaus claims that the short-run impact of a reduction in carbon intensity resulting from induced innovation is likely to be modest to that of a substitution of capital and labour for carbon energy in production, but he considers a restrictive set of production and innovation possibilities.[68] Popp's ENTICE model (2004) extends DICE in a different way by considering price-induced innovation. He shows that directed innovation in the energy sector can make an important difference. Popp presents a calibration exercise suggesting that models that ignore directed technological change do indeed significantly overstate the costs of environmental regulation.

An alternative approach has been to build on new growth theories, where technological change is by its nature endogenous (e.g. see Romer (1990) and Aghion and Howitt (1992)) to look at the interactions between growth and the environment. These papers have developed frameworks where growth is driven by innovations that are themselves motivated by the prospect of monopoly rents. 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. can decide whether to innovate in more or less carbon-intensive technologies or sectors.)[69] This work extends the early work on growth with environmental externalities (e.g., Plourde, 1972).

In contrast, learning-by-doing (LBD) models use the learning curve estimates to simulate falling costs for alternative energy technologies as cumulative experience with the technology increases. The tractability of learning curves has led to the use of learning-induced technological change throughout the literature, particularly in disaggregated or so-called "bottom-up" models.

One criticism of models using LBD 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

[68] Earlier work by Bovenberg and Smulders (1995, 1996) and Goulder and Schneider (1999) study endogenous innovations in abatement technologies.

[69] Other works investigating the response of technology to environment regulations include Grübler and Messner (1998), Goulder and Mathai (2000), Manne and Richels (2004), Messner (1997), Buonanno, Carraro, and Galeotti (2003), Nordhaus (2002), Di Maria and Valente (2008), Fischer and Newell (2008), Bosetti, Carraro, Massetti, and Tavoni (2008), Massetti et al. (2009), Grimaud and Rouge (2008), and Aghion et al (2009).

which learning occurs. As such, LBD models may give a false sense of comfort and precision that may belie the R&D or other resources that went into the technology development (Clarke and Weyant, 2002).

Goulder and Mathai (2000) provide a theoretical model that explores the implications of modelling technological change via R&D or LBD. When using R&D-based technological change, there are two effects of induced innovation on optimal abatement. While it reduces marginal abatement costs, which increases the optimal amount of abatement, it also increases the cost of abatement today relative to the future, because future abatement costs will be lower. The combination of these effects implies that with R&D-induced innovation, optimal abatement is lower in early years and higher in later years than it would otherwise be. In contrast, in the learning-by-doing model, there is a third effect: abatement today lowers the cost of abatement in the future.

A key question in this literature is the extent to which technological change can offset the cost of climate policy. Smulders and de Nooij (2003) and van Zon and Yetkiner (2003)provide theoretical models derived from the endogenous growth literature to address this question. Smulders and de Nooij find that while endogenous technological change reduces the cost of energy conservation policies, it does not offset these costs completely. In contrast, van Zon and Yetkiner note that using the revenues raised by an energy tax to provide an R&D subsidy may increase long-run growth, through R&D-induced technological change. Turning to simulation models, Popp (2004) finds that induced innovation increases welfare by 9% compared to a model with exogenous technological change. In contrast, Gerlagh (2008) finds greater potential for induced technological change is larger, with optimal carbon taxes falling by a factor of 2 and the cost of policy cut in half.

A key contrast between Popp (2004) and Gerlagh (2008) is the opportunity cost of investment. Assumptions about the source of new energy R&D play an important role in climate models. If new energy R&D replaces other forms of productive R&D, the benefits of induced R&D will be reduced. In contrast, the consequence of endogenous versus exogenous technological change through LBD is unambiguously positive: there is no opportunity cost other than the current cost of production. Thus, LBD models tend to provide more optimistic results about the potential of technological change than models using R&D-based technological change.

Given the range of possible outcomes depending on assumptions about crowding out, empirical evidence is important. Popp and Newell (2012) use patent and R&D data to examine both the private and social opportunity costs of climate R&D. Focusing on the alternative energy sector, they find evidence of crowding out for alternative energy firms, but note that the patents most likely to be crowded are innovations enhancing the productivity of fossil fuels, such as energy refining and exploration. This finding is consistent with the notion that any apparent crowding out reacts to market incentives: As opportunities for alternative energy research become more profitable, research opportunities for traditional fossil fuels appear less appealing to firms. This provides support for Gerlagh's result that crowding out is less damaging to the economy if carbon energy-enhancing technologies are crowded out.

3.12.5 Methods of inducing R&D—incentives, regulation and direct expenditures

The combination of environmental externalities and knowledge market failures suggests two possible avenues through which policy can encourage the development of climate-friendly technologies: correcting the environmental externality and/or correcting knowledge market failures. Because knowledge market failures apply generally across technologies, policies addressing knowledge market failures may be general, addressing the problem in the economy as a whole. Examples include patent protection, R&D tax credits, and funding for generic basic research. Such policies focus on the overall rate of innovation – how much innovative activity takes place. In contrast, policies aimed specifically at the environment focus on the direction of innovation. Although the latter group of policies includes policies regulating externalities, such as a carbon tax or cap-and-trade system, it also includes environmental and energy policies using more general R&D policy mechanisms with a specific focus on the environment, such as targeted government subsidies for the adoption of alternative energy and targeted funding for basic and applied research.

Studies evaluating the effectiveness of these various policy options find that environmental and technology policies work best in tandem. Although technology policy can help facilitate the creation of new environmentally friendly technologies, it provides little incentive to adopt these technologies (e.g. Popp, 2006; Fischer, 2008; Acemoglu et al., 2012).

Fischer & Newell (2008) use a micro approach to study a broader set of policies - including those encouraging technology adoption - to assess policies for reducing CO_2 emissions and promoting innovation and diffusion of renewable energy. Although the relative cost of individual policies in achieving emission reductions depends on parameter values and the emission target, in a numerical application to the U.S. electricity sector, they find the ranking (in terms of ascending aggregate cost) is roughly as follows: (*a*) emission pricing, (*b*) emission performance standard, (*c*) fossil power tax, (*d*) renewables share requirement, (*e*) renewables subsidy, and (*f*) R&D subsidy. Nonetheless, an optimal portfolio of policies—including emission pricing and R&D—achieves emission reductions at significantly lower cost than any single policy. Gerlagh and van der Zwaan (2006) find an emission performance standard to be the cheapest policy for achieving various carbon stabilization goals. They note that the ordering of policies depends on the assumed returns to scale of renewable energy technologies. Fischer and Newell (2008) assume greater decreasing returns to renewable energy, due to the scarcity of appropriate sites for new renewable sources. Thus, an important question raised by Gerlagh and van der Zwaan is whether the cost savings from innovation will be sufficient to overcome decreasing returns to scale for renewable energy resulting from limited space for new solar and wind installations.

Different policies have very different effects on technological change. In general, market-based policies are thought to provide greater incentives for innovation, as they provide rewards for continuous improvement in environmental quality (e.g., Magat, 1978, 1979; Milliman and Prince, 1989). In contrast, direct regulation penalizes polluters who do not meet the standard, but do not reward those who do better than mandated.

However, the effects of specific policies can be more nuanced. Fischer et al. (2003) find that the ranking of policy instruments depends on the innovator's ability to appropriate spillover benefits of new technologies to other firms, the costs of innovation, environmental benefit functions, and the number of firms producing emissions. Bauman et al. (2008) raises the possibility that command-and-control policies may induce more innovation when pollution is reduced by changing processes, such as using cleaner fuel or using a more efficient boiler, rather than by end-of-the-pipe solutions.

The ambiguous predictions of theoretical models make empirical evidence of the effects of various policy instruments on innovation important. Johnstone et al. (2010) examine the effect of different policy instruments on renewable energy innovation in 25 OECD countries. They compare price-based policies such as tax credits and feed-in tariffs to quantity-based policies such as renewable energy mandates and find important differences across technologies. Quantity-based policies, such as renewable energy certificates, favour the development of wind energy. Of the various alternative energy technologies, wind has the lowest cost and is closest to being competitive with traditional energy sources. As such, when faced with a mandate to provide alternative energy, firms focus their innovative efforts on the technology that is closest to market. In contrast, direct investment incentives are effective in supporting innovation in solar and waste-to-energy technologies, which are further from being competitive with traditional energy technologies.

These results suggest particular challenges to policy makers who wish to encourage long-run innovation for technologies that have yet to near market competitiveness. Economists often recommend using broad-based environmental policies, such as emission fees, and letting the market pick winners. Such an approach leads to lower compliance costs in the short run, as firms choose the most effective short-term strategy. However, this research suggests complications for the long run. Because firms will focus on those technologies closest to market, market-based policy incentives do not provide as much incentive for research on longer-term needs. This scenario suggests a trade-off: Directed policies such as investment tax credits or technology mandates more effectively encourage the deployment of more expensive emerging technologies that are not yet cost-effective. However, this raises the costs of compliance, as firms are forced to use technologies that are not cost-effective. One possible solution here is to use broad, market-based policies to ensure short-run compliance at low costs, and use support for the research and development process to support research on emerging technologies. Thus, the focus is on continued improvement for emerging technologies, rather than on deployment of them.

3.12.6 Technology transfer

3.12.6.1 International Policy Framework

The UN Conference on Environment and Development (Rio 1992) gave a central role to technology transfer to developing countries, as well as the development of endogenous technology in these countries. The UN Framework Convention on Climate Change contains several provisions in which developed countries make commitments on technology transfer (Articles 4.3 and 4.5).

3.12.6.2 Process of technology development and transfer

Technology transfer has long been at the centre of scholarly debate on economic development (Rosenberg, 1970). Work on international technology transfer has built on the basic idea that technologically – advanced developed countries can assist developing countries to access and grasp technology. Modes for technology transfer that have been identified include trade in products, trade in knowledge and technology, foreign direct investment, and international movement of people (Hoekman et al., 2005). Phases and steps for technology transfer involve absorption and learning, adaptation to the local environment and needs, assimilation of subsequent improvements, and generalization (Foray, 2009).

Technology transfer plays a role in the different stages of industrial development. Three stages of industrial development – initiation, internalization and generation – have been identified (Lee et al., 1988, p. 242; Correa, 2007). Corresponding to each stage is a level and type of technological development, and technology needs.

Another useful concept used by analysts is the technological “catch-up” or “leap-frogging” that developing countries undertake in order to narrow the gap between them and the leading countries (Abramovitz, 1986). Two stages of the catch-up process have been identified. The first is an early catch-up stage in which simple technologies are adopted in mature low-tech and medium-tech industries. The second is a late catch-up stage in which more complex technologies are adopted in medium and high tech industries (Kim and Dahlman, 1992). Three broad phases of learning and innovation are also identified: first, the initiation of production by importing foreign technology; second, local diffusion of new products and processes; and third, industrial upgrading through incremental technological improvements to process and product design and marketing improvements. The right policies to promote technological learning are different during the early and later stage of the catch-up process, and different policy measures are thus required. At the first stage, technology development is acquiring the capability to use existing technology and to adapt and improve the technology. The second stage requires innovation, including design and engineering skills and associated organizational and marketing skills.

3.12.6.3 Technologies in the Public Domain and Patented Technologies

The issue of whether the status of proprietary rights has an effect on transfer 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. Regarding patented technologies, much of the debate is centered on whether the temporary monopoly conferred by patents has resulted in obstacles to access to technology.

It is widely accepted that patents have the function of providing incentives for innovation, so that the inventor or company that provided the financing can recoup the innovation costs. There is however a discussion whether the prevailing patent regime represents a fair balance between the incentives provided to the patent holders and the welfare interests of the public, whether it facilitates or hinders technology transfer. Clearly it is a valid question whether the present system is "optimal" thus requiring no reform, or adjustments are needed, particularly with regard to developing country access to technology

Proponents of a strong intellectual property (IP) regime have argued that patents boost technology transfer because the patent applicants have to disclose information on their claimed invention when submitting their application. Some analysts have also pointed out that in some sectors of climate technology, particularly renewable energy such as wind and solar technology, there are easily available substitutes and sufficient competition, such that patents on these technologies do not make them costly or prevent their spread. A study by Barton (2007) on three sectors (solar photovoltaic, biofuels, and wind technology) found that despite patents being prevalent in these sectors, competition between the various types of energy kept prices and costs relatively low.

Some recent studies that analysed specific sectors of climate related technologies have also pointed out the potential for IP protection for becoming a barrier to technology transfer (Lewis, 2007; Ockwell et al., 2007; Ockwell, 2008).

3.12.6.4 International cooperation for technology development and transfer

Various international agreements on climate change, trade, and intellectual property include provisions aimed at facilitating technology transfer to developing countries. In climate change agreements, these provisions have aimed to encourage participation of developing countries in the agreements and to address barriers for technology adoption, including the need for financing (Metz et al., 2000). However, the provisions have been found by some scholars to be ineffective, lacking mechanisms to ensure the effective transfer of technology to developing countries (Moon, 2008).

One important area of technology cooperation is in research and development. Issues that can be addressed include: (1) whether the cooperation mechanisms are "pull" or "push" mechanisms, based on incentives that operate on the demand (for example, advance purchase contracts) or on the supply (for example, subsidies for research); (2) the type of R&D to be conducted; (3) the thematic fields selected for R&D; (4) the type of cooperating parties (public, private, mixed); (5) the policies regarding generation and availability of R&D results for utilization or further research (IP issues); and (6) the organizational structure of the R&D activities.

3.13 Research needs

As is clear from even a casual reading of this chapter, there are many questions that are not completely answered by the literature. It is prudent for our assessment to end with our opinion of where research should be directed over the coming decade so that the AR6 may be able to say more about the ethics and economics of climate change.

3.14 Frequently asked questions

[Note from the TSU: FAQs will be presented in boxes throughout the text in subsequent draft]

FAQ 3.1: 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 ethical concepts?

Decision-makers and the public are concerned with what ought to be done about climate change, even though reasonable people have differing views on this issue. What ought to be done, at least in contexts that involve values and human interests, is the subject matter of ethics. The contribution this chapter makes is in reviewing how the literature views this question.

FAQ 3.2: What factors are relevant in considering responsibility for future measures that would mitigate climate change?

Law provides useful guidance for how societies have dealt with actions that end up being more harmful than previously thought. Under the two primary legal systems in the world (common law and civil law), responsibility for harmful actions is generally a basis for liability only if the actions breach some legal norm such as negligence or nuisance. Negligence is based on the standard of the reasonable person. Nuisance liability does not exist if the actor did not know or have reason to know the effects of its conduct. Both legal systems would require inquiry into whether emission of greenhouse gases falls into a defined category of wrongful conduct. If some or all past emissions satisfy that standard, the next issue in both common law and civil law countries would be the nature of the causal link with the resulting harm.

FAQ 3.3.: What criteria should policy makers use when developing policies and measures to mitigate climate change?

In addition to reducing GHG emissions, climate policy may have many other objectives. Here, we organize these many objectives into four broad categories. First, climate policy may have economic objectives that involve lowering economic costs, including transactions costs, losses in economic efficiency, and any adverse effects on economic development, innovation, and growth. Second, climate policy may have distributional objectives. It may need to avoid interfering with goals to alleviate poverty, if it is to be viewed as fair. These distributional considerations are often decisive in the political sphere. Third, climate policy can have multiple environmental objectives at the local, regional, and global levels. Fourth, climate policy will need to be institutionally feasible for it to be adopted, in terms of administrative burden and other political considerations.

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