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DECISION MAKING FRAMEWORK TO ADDRESS CLIMATE CHANGE

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CHAPTER 2

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**DECISION MAKING FRAMEWORK TO ADDRESS
CLIMATE CHANGE****IPCC Working Group III
Writing Team II****TABLE OF CONTENTS**

2.1 Introduction	1
2.1.1 Questions and issues	1
2.1.2 Climate change uncertainties and their relationships	2
2.1.3 SCOPE OF THE CHAPTER:	6
2.2 NATURE AND GENESIS OF THE CLIMATE CHANGE PROBLEM LEADING TO THE FCCC	7
2.2.1 CONCENTRATIONS NOT EMISSIONS:	7
2.2.2 ABSORPTION CAPACITY:	8
2.2.3 NATURE OF RISK:	8
2.2.4 COMMON BUT DIFFERENTIATED RESPONSIBILITIES:	9
2.2.5 FCCC AS A KEY ELEMENT FOR DECISION MAKING	10
2.3 COLLECTIVE DECISION MAKING	11
2.3.1 HOW AND WHY COLLECTIVE DECISION MAKING:	11
2.3.2 FACTORS FOR COLLECTIVE DECISION MAKING:	12
2.3.2.1 Vulnerability of food production systems:	12
2.3.2.2 Anthropocentric Vs Ecocentric approaches:	13
2.3.2.3 Poverty and Climate Change:	14
2.3.2.4 Intergenerational equity and discounting:	15
2.3.3 IMPLICATIONS OF COLLECTIVE DECISION MAKING:	16
2.3.3.1 Cost of delay and slippages (Free riding through delay):	16
2.3.3.2 Valuing Common Property (and Paying for It):	17
2.3.3.3 Accepting Adaptation:	18
2.3.3.4 North-South transfers:	19
2.4 PROCESS OF COLLECTIVE DECISION MAKING	20
2.4.1 A SUMMARY OF THE STEPS IN ITERATIVE DECISION MAKING:	21
2.4.2 CRITERIA FOR INTERREGIONAL ALLOCATIONS:	22
2.4.3 NORTH-SOUTH COOPERATION	24

2.5 Economic Formulation of Individual and Collective Decision Making	27
2.5.1 Accommodating the supplementary uncertainty caused by climate change	28
2.5.1.1 Strong uncertainty	29
2.5.1.2 Abrupt change adds unpredictability to uncertainty and risk	30
2.5.2 "Rationalities"	32
2.5.2.1 Utility-based decision criteria	33
2.5.2.2 Bounded rationality	35
2.5.2.3 Procedural rationality	35
2.5.3 Responses to uncertainty and risk	36
2.5.3.1 Uncertainty and risk decision rules	37
2.5.3.2 Decision analysis techniques	38
2.5.3.3 Addressing strong uncertainty	39
2.5.4 Collective decision making	41
2.5.4.1 Steps in negotiating international environmental treaties and agreements	42
2.5.4.2 Collective decision criteria	43
2.5.4.3 Decision procedure	44
2.6 A Sequential Decision Making Framework to Hedge Against Impacts of Uncertainty and Change	46
2.6.1 Decision making paths: Which strategy would be best?	46
2.6.1.1 Scenario analysis	46
2.6.1.2 Sequential decision analysis	47
2.6.1.3 Clearing up the uncertainties? The value of improved information	50
2.6.2 Exploring mutual insurance decisions and markets for risks	52
2.6.2.1 Use of financial markets	53
2.6.2.2 Insurability of risks associated to climate change	54
2.6.2.3 A market framework to respond to collective risks	55
2.6.3 Portfolio analysis analogy	58
2.6.3.1 Selecting a portfolio	59
2.6.3.2 No operational model is available	60
2.6.3.3 Three main forms of policy options	61
2.7 REFERENCES	66

Chapter 2

DECISION MAKING FRAMEWORK TO ADDRESS CLIMATE CHANGE

Summary for 2.5 & 2.6

Decision makers face strong uncertainties that are characterised by insufficient knowledge and lack of information. There also is the possibility of large damages (low probability) whether climate change is abrupt or not. In addition, models in the North do not usually build in the perspective of the South. The presence of strong uncertainty, however, does not mean inaction. It means filtering paths of action and choosing which strategy with which outcome would be best.

Decision theory leads to the assessment of alternative strategies and the valuation of likely outcomes. As a consequence of insufficient knowledge and data, predictions of the rate and extent and timing of climate change and their effects have been made in terms of scenarios rather than in usual probabilistic terms. This situation reflects the gap between the information that is available on climatic processes and economic effects and the one that would be relevant to Bayesian inference. Bayesian scheme has two limitations with respect to climate change: first the existence of strong uncertainties and, second, the existence of low probabilities attached to large potential damages. Alternatives, however, are available: risk assessment (Chapter 7), fuzzy logic, or evidence theory.

Economic criteria for choice explicitly or implicitly are utility-based criteria. Ultimate choices are made by individuals. Yet, because climate change engages considerations that are new in their globality and relate to unusual time-spans, choices also concern collective decision making. Under collective decision making, the valuation of outcomes is matter of negotiation.

The decision making framework to address climate change is made of strategies at three different levels. *Sequential decision making*. Sequential decision making paths are elected to hedge against uncertainty and change. "Act-then learn" (then act) decision strategy would be best. Hypothesis: there is an agreement that uncertainties cannot be resolved before a decision is taken. *Exploring insurance analysis*. The word 'insurance' is sometimes abused in climate debate. Yet, the insurance industry (individual, fixed, short-term contracts) cannot afford climate change related risk sharing. New institutions should be envisaged, e.g., a market framework with new financial institutions, mutual contracts and securities to deal with collective risks. *Constructing a portfolio of policy measures*. Numerous policy measures are available to limit the impacts of climate changes. The decision maker's problem is much more complex than the choice of a single policy measure to the exclusion of all others. In practice, it is a question of constructing a *portfolio* of policy measures.

Jan. 18, 1995

2.1. INTRODUCTION

Framework convention of climate change (FCCC) signed by many heads of state at Earth summit at Rio in 1992 has been ratified by more than 50 countries by March 1994 and is now legally binding. To carry out the deliberations of this convention, a decision making framework is needed that encompasses global and national concerns. While short-term decisions are governed by FCCC, there are some long-term considerations, say for several decades, which also need to be looked into in the decision making framework by interpreting their consequences until 2050 and beyond. In the present chapter we construct such a framework.

2.1.1 Questions and Issues:

Climate change due to accumulation of greenhouse gases (GHG) in the atmosphere poses many economic, political and scientific challenges which have to be dealt with in a collective decision making framework by national and international decision making bodies. Policy decisions to address climate change have to be taken in a complex setting characterized by uncertainty. Apart from uncertainties, these decisions often involve use of conflicting criteria such as equity, efficiency, sovereignty and ecological concerns.

Decisions are usually based on one's beliefs about the likely occurrence or not of uncertain events which are relevant to the decisions at hand. The decision regarding climate change have to be made not only in the near future, but have to be reviewed on a continuous basis, or at least periodically. The major decisions concerning climate change that need to be faced by all countries and their citizens are:

1. What should be the level of concentration of GHG gases that can be tolerated at different times?
2. By how much should GHG emissions be reduced to achieve these chosen levels of tolerable concentrations?
3. How should these abatement levels be distributed among countries taking into account the

responsibilities for current concentrations and development needs? In other words, who should bear the burden of emissions abatement at different phases?

4. What kind of policies will achieve the desired reductions of concentrations of GHG gases and in turn, the emissions?
5. Considering that uncertainties will always remain, shall we wait for more precise information that reduces uncertainties? If we want to collect more information, and since collection of information is expensive, on what aspects of uncertainties should we concentrate? In this connection, we note that according to the earlier IPCC report, even present information is adequate to go for the goal of reducing global emissions by 60% for stabilisation.

To answer these questions, a framework is needed which will be characterized by uncertainties at all levels. We say that a decision situation is governed by uncertainty if the consequences of decisions and the state of nature are not known apriori. The agent(s) who makes the decisions is known as the decision maker(s) (DM in short).

2.1.2 Climate change uncertainties and their relationships:

It is fair to say that most decisions are made under some uncertainty or other. Consider for example, the uncertainties in decision to invest in an energy supply system. During the lifetime of the project there could be changes in demand, interest rates, availability of alternative technologies and environmental and other regulations that may change from time to time. However, the uncertainties of climate change decision making are different from other decisions because:

- Climate change decisions have to be taken collectively and not by a single entity;
- The consequences of these decisions affect everyone differently and for a very long term (Distributional/regional effects).
- Any decision made now with wrong outcome can only be identified after a long lag, by which time it might be too late.
- It is subject to non-linearity and can lead to large damages, irreversibility and even catastrophic surprises.

That there is a rise in the accumulation of GHG is agreed upon by everyone. What is

uncertain is the extent of climatic impacts such as rise in temperature, rise in sea level or occurrence of extreme events and thereby changes in ecological balances in biosphere. Some expect that in the long term, efforts to contain these impacts and offsetting them would have significant economic costs. However, there are others who say that there are additional benefits in undertaking "hedging strategies" (see box) such as savings of fuel, local pollution, traffic congestion and so on. The uncertainties concerned with the climate change debate here can be classified into the following categories:

1.

Scientific uncertainties regarding the effects of emissions of GHG on climate change characterized by several important variables among many others, viz., mean temperature rise, sea level rise, precipitation changes and changes in frequency of extreme events such as floods, cyclones and draughts. One could also call these uncertainties relating to geographical and atmospheric changes. The interrelationships among these variables for a given level of concentration are also uncertain. These are dealt with by working group I of IPCC.

2.

Impact uncertainties corresponding to each of the above scientific uncertainties where it is not clear how much impacts different levels of climatological variables will have on, say, biomass productivity, eg., that of agriculture and forests, species loss - terrestrial and marine, and other discomfort and damage. These are dealt with by working group II of IPCC.

3.

Economic uncertainties (corresponding to impact uncertainties) concern the effects of Climate Change on national and therefore individual incomes due to physical impacts such as coastal erosion or cost of increased airconditioning. Cline (1992) has elaborated these and calls them as benefits of avoiding climate change. Both the costs and benefits of abatement are uncertain. Costs of abatement could be different for each region and could have different impacts on GDP growth of different nations. However, the uncertainties regarding the costs of abatement measures are less than those associated with the benefits these measures bring. Here again, the same level of geophysical impacts could lead to different economic impacts to countries at different levels of economic development. Several chapters in the present report deal with economic and technological uncertainties, viz., chapters 7 and 8.

4.

Technological uncertainties concern the timely availability (lead times) and cost of reliable

technologies and their impacts on reducing emissions. As shown by Hafele et al. (1981), it takes nearly forty to fifty years for a new energy carrier to capture 50% of the market from the time it captures 1% of the market. Judging by this thumb rule, there are not many technologies to look forward to in the very near future. Though many technologies look promising, they have yet to enter in global energy balances. Even if there are many successful demonstrations of carbon free technologies, the ultimate test is to enter the global energy balances, which at present still consist of coal, oil, gas, hydro and nuclear energy¹. In fact, it is possible that nuclear energy which is a part of the global and national energy balances today, might make an exit without reaching its full potential. Thus, lead times required for transition in energy system are very large. The lead times required for abatement technologies to be effective and extent of abatement possible by each, thus, become important factors in decision making.

2.1.2.1 Relating scientific uncertainties with impact uncertainties:

How are these uncertainties related? If one could structure the relationships among them, decision making can be guided with better understanding rather than getting overwhelmed by uncertainties, and some action paths can become obvious. Scientific uncertainties concerning the changes in climate variables for a given concentration level, can be linked with impact uncertainties as follows. Considering only the temperature variable, figure 2.1 illustrates that for low levels of climate change one could be in the zone of adaptation. Further emissions could lead to higher concentrations, that could increase temperature and increase damages. Say, at $\Delta t=2^{\circ}\text{C}$, there could be "discomfort" zone; but, with some positive probability, this zone could mean disaster for some. We refer to disaster as "an event occurring suddenly and causing great damage or hardship". For example, a small percentage in sea level rise might cause serious damages only to Bangladesh and Maldives but, might not have as much effect on the rest of the globe. On the other hand, we define catastrophe as "a sudden and widespread disaster." This can occur with a very small probability for say a temperature rise of 4°C but with a higher probability with a temperature change of 6°C . This has to be avoided because apparent and hidden costs of global and local irreversible damages and extensive adaptation are high. Figure 2.1 shows that as the GHG accumulation increase, the severity of damages could increase.

¹ Biomass consumed in developing countries in the form of fuel-wood, crop residues and animal dung are not recorded satisfactorily. They provide 10% to 90% of household energy for cooking in many developing countries.

2.1.2.2 Relating impact uncertainties with economic uncertainties:

Now we shift from "damage" to "damage costs" and what they could mean in terms of economic impacts to a country. Damages have different impacts on different countries for three reasons.

I. Impacts themselves may be higher in geophysical terms. For example, for a given rise in global mean temperature, sea level rise in Indian subcontinent could be higher than in, say, North America.

II. Even the same change say, 1°C temperature rise, could have more impact at 25°C average temperature than at location with 15°C average temperature.

III. Even for identical climate change, adaptation to climate change imposes greater burden on poor countries than rich countries, i.e., the same amount of adaptation costs say, \$1 billion, could have different economic impacts due to differences in population, economic resources and technological capability.

When damage costs for adaptation are considered, as figure 2.2 shows, the zone for acceptable costs for a poor country compared to a rich country may be much smaller and the disaster zone may be much wider beginning at a modest level of climate change.

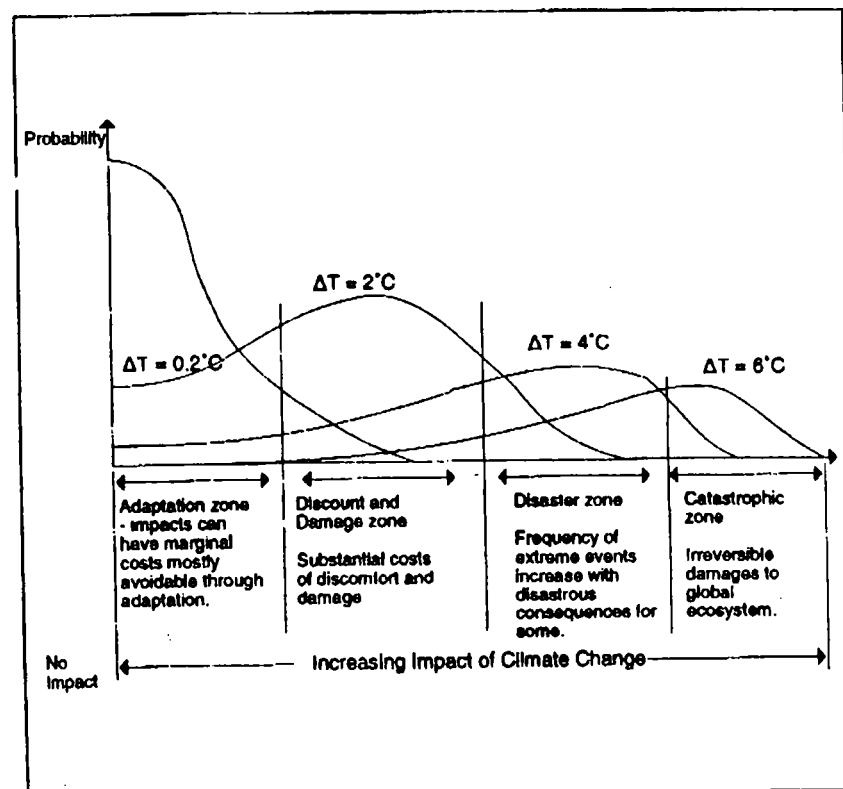


Figure 2.1: Schematic linkage between scientific uncertainties and impacts

Area under each probability distribution curve is 1. At $\Delta t = .2^{\circ}\text{C}$, the probability that there is no or little impact is much larger than at $\Delta t = 6^{\circ}\text{C}$. Reverse is the case for catastrophic zone. Different curves are meant to represent qualitative differences between "small" climate change and "large" climate change, and the range of temperatures corresponding to each curve remains a subject of discussion. Similar relationship may be there for different levels of sea level rise.

DIFFERENT WELFARE IMPACTS FOR THE SAME CLIMATIC DAMAGE : AN ILLUSTRATION

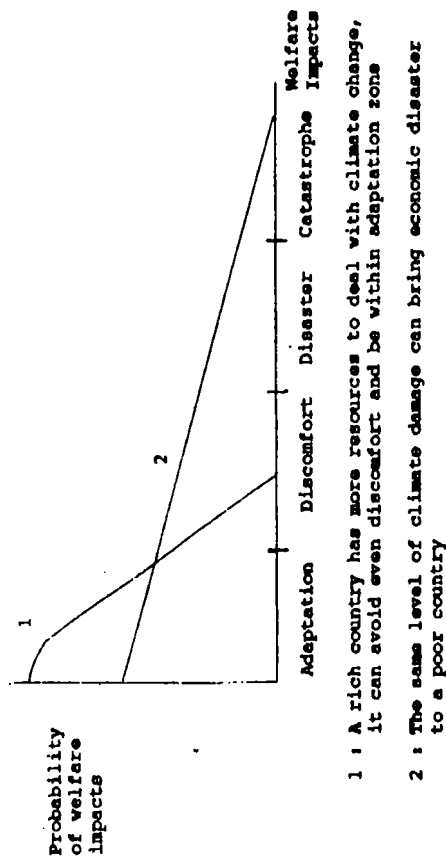


Figure 2.2

We have assumed that adaptation to climate change imposes greater hardship on poor countries than rich countries for identical climate impacts.

Hence, in this chapter we undertake a detailed analysis of the consequences of various issues and attitudes, such as, equity, poverty, ecocentric approach and discounting, information uncertainty and distributional effects for climate change decision making problem marked by uncertainty.

2.1.3 Scope of the chapter:

This chapter raises the *basic questions* involved in climate change decision problem; it emphasizes the *collective nature of the decisions* to be taken at the international level; it focusses on the various *issues related to climate change decision* such as vulnerability of food production systems, poverty, cost of delay, free riding, valuing common property, inequalities in responsibilities, North-South transfers, and ecocentric views; and it provides the *linkages between various components of the sequential climate change decision problem*. It also discusses various *decision tools* such as the utility based criteria, the nature of uncertainty, risk and non-linearity, the role of time, insurance and portfolio approaches to climate change.

To address the climate change decision problem, one should know what are the questions. Section 2.1 raises all the relevant questions related to climate change decision making and the various uncertainties related to climate change and their interrelationships are also discussed. Section 2.2 gives an overview of the nature and genesis of the climate change decision problem; this section includes topics such as concentrations, absorption capacity, nature of risk and inequalities in responsibilities. Section 2.3 presents factors that affect collective decision making. In section 2.3.1, how and why of collective decision making are analyzed. Various considerations that go into collective decision making such as vulnerabilities, ecocentric views, poverty, and intergenerational equity are covered in section 2.3.2. The implications arising out of collective decision making such as cost of delay, valuing common property, accepting adaptations and North-South transfers are dealt in section 2.3.3. In section 2.4, under the heading of process of collective decision making, we look at the steps involved in iterative decision making, criteria for inter-regional allocation, and North-South co-operation through global policy instruments. The economic notions of uncertainty, risk, bounded rationality, as well as various decision tools are discussed in section 2.5. Finally, in section 2.6, we provide a sequential decision making framework to hedge against impacts of uncertainty and change. This framework is made of three components, namely, decision making paths, mutual insurance decisions, and

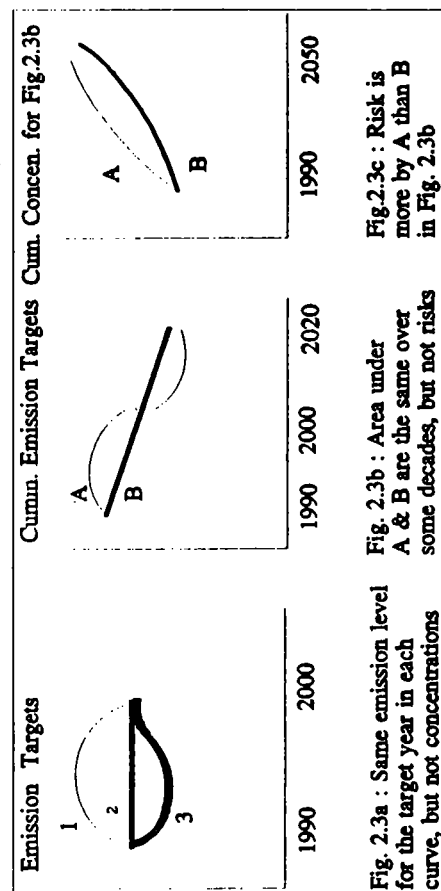
2.2 NATURE AND GENESIS OF THE CLIMATE CHANGE

PROBLEM LEADING TO THE FCCC

2.2.1 Concentrations not emissions:

The climate change problem is one of increasing concentrations (i.e. accumulation of gases over decades) and not just emissions in a given year (stock and not flows) of GHGs. Of course, to contain the increase in concentrations, one has to worry about the rate of emissions as well. At present targets are being discussed in terms of emission levels, say reaching 1990 level by 2000. However, consequences of each path to 1990 levels have to be worked out in terms of concentrations (Fig.2.3a). While there is a discussion on reporting emissions every year at the Intergovernmental Negotiating Committee (INC), the concentration levels as shown in Fig.2.3b, are yet to be discussed. Both shape and area under emission curve are important, since risks are measured in CO₂-years. Hence, climate change decision problem need to be addressed in terms of concentrations where earlier reductions should be rewarded to account for their more beneficial consequences and to encourage early actions. If we decide to wait for more information without acting, the stock of concentration of the order of 750 billion tons, since pre-industrial times gets larger, passing a larger burden to future generations.

EMISSIONS, CONCENTRATIONS AND CLIMATE CHANGE RISK



In Fig.2.3a, the emission levels in the target year are the same for all paths, but each path has obviously different implications in terms of cumulative emissions. Fig.2.3b shows that the cumulative emission targets are the same for paths A and B i.e., area under each path is the same. However, as shown in Fig.2.3c, the climate change risk is more under path A than path B due to higher "CO₂-years" in the atmosphere. Therefore, earlier reduction should be rewarded.

Figure 2.3

2.2.2 Absorption capacity:

The difference between cumulated emissions and atmospheric concentrations is due to absorption capacity of the atmosphere. Due to lack of understanding this is often represented as a factor by which one reduces cumulated emissions.

Greenhouse gas emissions are absorbed by forests, oceans, agriculture and so on. Thus, not all emissions end up as concentrations in the atmosphere. While some hold a view that absorption capacity, also known as sinks, may increase slightly with increased concentrations, others consider that this is eroding fast due to denuded forests and polluted oceans. Assuming that about 4 billion tons of carbon dioxide is annually absorbed by the sinks, one implication could be that if humanity lived a lifestyle corresponding to about 0.66 tonne of carbon equivalent emissions per person, per year, there would be no rise in atmospheric concentration of greenhouse gases from current levels. This figure is applicable for the present population levels. According to this principle, those who emit less than this amount may not be considered responsible for climate change effects. In other words, responsibility of marginal damage begins after going above this limit. However, is this the right way to allocate absorption capacity? This is an important issue. While absorption capacity of forests and agriculture could belong to the state in which they are, capacity of oceans is a common global property. There is a need to understand how absorption takes place and how the sink capacity can be distributed.

2.2.3 Nature of risk:

Climate change risk is a trend risk and not a sudden risk, or a random event say as in nuclear accidents, earth quakes or floods. That is, if there is a risk at time t , then, there will be similar risk at time $t+1$.² However, correspondingly there would be a stream of benefits of abatement, i.e., if there is benefit at time t , there will be benefit at $t+1$ also, and they are additive. This has two implications: once climate change impacts get in motion, it would be difficult to halt them. Corollary of that is, that the problem has to be addressed in a systematic fashion by reducing the trends of growth, i.e., more like gradually decelerating a car, rather than swerving to avoid an accident. Second, higher abatement costs are justified in case of trend risk, as it has stream of benefits for all years starting after a given year, in distant future. That is, abatement avoids adaptation costs not in say, 2025 but for many years subsequently.

² That is, presently, there is 750 giga (billion) tons of carbon equivalent greenhouse gases in the atmosphere accumulated due to human activities. If there is risk at time t , then the risk at time $t+1$ will be similar.

Therefore, small but regular reductions may be desirable than hoping to reduce suddenly and a lot later, which can be traumatic, if not impossible. It is better to initiate efforts to be on the learning curve which is gradual. If new information suggests that scaling up is not required, one could relax. However, in the meantime due to learning experience, understanding of how to deal with it develops. One could compare this with developing and testing fire fighting systems before the fire breaks, not after. This capability is to be developed as early as possible. As pointed out by Chichilnisky (1994), climate risk is endogenous, collective and correlated. Delay in response is associated with two risks: (a) need to adapt to the changes and (b) irreversible damages. Can irreversible damages, say, by extreme events, be compensated by insurance? The bigger issues such as increased costs and damages due to temperature rise, sea level rise, loss in biodiversity and other unforeseen damages are unlikely to be covered by the insurance industry. Therefore, COP may need to exogenously decide on a risk minimization strategy in terms of concentrations of GHG, which the North could lead. For more details, refer chapter on equity.

2.2.4 Common but differentiated responsibilities:

Climate change problem is beset with most difficult problem of inequalities in responsibilities. Annex I continues to emit 70% of CO₂ emissions and has been responsible for 85% of the cumulated emissions from the pre-industrial period and 77% from 1950 onwards. Decisions to reduce would have been easier, if there was equality among nations. Many non-Annex I countries have inadequate living standards with insufficient nutrition, provision for safe drinking water and access to sanitation.³ Nearly, 20% of them do not have even light bulbs. It is not correct to say that everyone emits. In the next 5 decades despite expected rise in South's emissions, concentrations contributed by North would be larger than the concentrations contributed by South, even if North goes back to the 1990 levels and reduces further. Therefore, there would have to be simultaneous trends of the rich (viz., North) reducing and the poor (viz., South) increasing their emissions, to give south the time needed to develop and fulfill basic needs. Here, the North has a stake in South's development. That is, to see that South pursues on path that requires least greenhouse gas emissions for given development goals. If, North's contribution to past and future concentrations are put to zero, South can go on with its development for another century without worrying about the climate problem. This

³ The non-Annex I countries are not homogeneously poor, but, on average their living standards are much below that of Annex I countries. We also note that there are poor in North and rich in South.

point is analyzed in detail in the section on North-South transfers.

2.2.5 FCCC As A Key Element For Decision Making

Some of the features described above are directly or indirectly incorporated in the FCCC. Some may yet guide future negotiations. The following features of Framework Convention on Climate Change (FCCC) are relevant for the decision making framework.

1. Objectives: The ultimate objective is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.
2. Principles: The parties should protect the climate system in accordance with their common but differentiated responsibilities. The developed countries should take the lead in controlling climate change. The specific needs and special circumstances of developing countries should be given full consideration.
3. Commitment: Developed country parties should take lead to adopt national policies and measures by limiting their anthropogenic emissions of GHGs so as to modify longer term trends. In order to promote progress to this end, each of these parties shall communicate detailed information on measures taken with the aim of returning individually or jointly to their 1990 levels of these anthropogenic emissions.
4. Technology transfer: It also supports technology transfer and training to developing countries by developed countries.
5. Incremental costs: Global Environmental Facility (GEF) would be set up to provide "full agreed incremental costs" to developing countries, when needed.

Keeping these FCCC guidelines in view, we discuss various issues related to climate change decision making in this section.

2.3 COLLECTIVE DECISION MAKING

2.3.1 How and Why collective decision making:

The Conference of Parties (COP) will be the apex forum which makes the collective global environmental decisions for global welfare within the constraints set by equity and efficiency. A conservative choice gives South the space it needs to grow and develop and future generations more options to choose from. However, it can not be too conservative so as to deprive the present generation. There is a hierarchy of decisions involved here.

Climate change means different things to different people. To Annex I countries, it is the cost of abatement, to non-Annex I countries it is the burden of adaptation, and concern for vulnerability, irreversible damages and rise of frequency of extreme events and most of all costlier development. To island states, it is their existence and to oil exporters, it is their revenue loss, if fossil-fuel demand drops. Again, it concerns differently economists and environmentalists. All these concerns need to be voiced in a comprehensive manner.

First stage as pointed out in section 2.1, involves decisions at global level, such as choosing concentration level stabilization and emission growth paths and their interregional allocations. These decisions have to be taken collectively (by the COP). Utility based criteria (see box 2.3, section 2.5.1) would be quite inadequate for this purpose. Global climate change will affect each country differently. Their risks and welfare costs are different. At the same time, those who have to take major abatement actions and therefore bear the costs of abatement are in general different countries from those who are at largest risk from climate change. We do not have a global welfare function that integrates the utilities of different stakeholders. Since global climate change affects every country, each country is a stake holder. In fact, since developing countries are more vulnerable and have contributed little to the pollution so far, they could have unequal rights, and could have more say in this matter. In fact, even in levying income tax, certain limits on taxable income is recognized widely and also progressive income tax. It is seldom that polluters decide what level of pollution could be tolerated particularly when they are less vulnerable to the possible impacts of the pollution. Yet, their difficulties in responding quickly has to be kept in view. In such a situation one can use risk based criteria, discussed later in this chapter. We discuss below the factors to be kept in view while choosing the level of risk.

2.3.2 Factors for collective decision making:

2.3.2.1 Vulnerability of food production systems:

FCCC suggests that "... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystem to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner --". Parry & Rosenzweig's study (1994) provides an idea of what is in store for future due to climate change in terms of food vulnerability.

They provide global assessment of the potential effects of climate change on crop yields, world food supply, and regions vulnerable to food deficits. The national yield changes for the climate change scenarios were used as inputs into a world food trade model, the Basic Linked System (BLS), developed at IIASA by Parikh K. et al (1988) and Fisher et.al. (1990). Simulation outputs from the BLS provided estimates of changes in cereal production, food prices and the number of people at risk of hunger.

The study concludes that the world cereal production is estimated to decrease between 1 and 7%, depending on the climate change scenarios used, by 2050. The study also indicates that the impacts would be more severe on developing countries, in comparison with developed countries. With farm level adaptations, reduction in global cereal production is expected to be between 0 and 5%. However, the largest negative changes would occur in developing countries. While, in the North (including China) there would be an increase in cereal production to the tune of 2 to 14% after taking into account the direct physiological effects of CO₂ and the farm level adaptations, there would be a decrease in developing countries to the tune of 6 to 12% even after taking the fertilization effects of carbon dioxide and the farm level adaptations. This loss of production in developing countries, together with rising agriculture prices, according to the study, is likely to increase the number of people at risk of hunger, in the order of 5-50%, depending on the GCM scenario.

Thus, CO₂ concentration levels of double the value of preindustrial values in 2060 may not be acceptable to the South. If 550 ppm is reached in 2060 AD, it is likely that given the long lead times required, stabilization reached by say, 2100 AD, would be much higher and the outcome may be severe.

2.3.2.2 Anthropocentric Vs Ecocentric approaches:

So far, we have viewed climate change decision making purely from the point of homo sapiens. At this juncture we want to emphasize the existence of an alternative viewpoint, viz., that of ecocentricism, which gives adequate, if not equal weightage, to all the living species in the world.

Climate change may affect flora and fauna and their habitats, such as coral reefs and physical environments that are a part of life support system. The earlier IPCC impact assessment indicates substantial pressures on biosphere and biodiversity due to climate change. For example, bleaching of coral reefs is expected. Due to the movement of temperature zones, without the rest of the life support system, species loss on land and sea is indicated. As we mentioned earlier, such a loss of species or damage to biodiversity has been traditionally ignored in the decision making framework. Only recently researchers have started developing tools such as Environmental Impact Assessment to study the value of biodiversity for the humans. Such studies are mostly anthropocentric valuations, carried out to find impact of the biodiversity loss on human recreation, medicines, education, research, chemicals, bio-engineering etc.

An ecocentric view, on the other hand, views homo sapiens as one of the species on the planet earth expected not just to live in harmony and balance with other species but also to share the biosphere (which includes oceans, rivers, atmosphere, etc.) which provide sustenance to other species too. To put it sharply, humankind's abrogation of decision making powers regarding nature is questioned. The ecocentric view proposes to curtail such decision making power. This view extends the ethical stand to include other animals and plants; Equity is not only among human beings but also between humans and other living species.

Though ecocentric viewpoint may seem extreme, it raises one crucial point. The link between the existence of other species and that of the human beings should be kept in mind while making any decisions regarding the activities of humans which would adversely affect the environment and *inter alia* other species.

2.3.2.3 Poverty and Climate Change:

Another important issue while making climate change decisions is that of poverty and the linkages between poverty and climate change impacts. Suppose there is increased occurrence of extreme events such as floods, cyclones, typhoons, hurricanes and so on occur due to climate change. Then, in such a situation, it is the poor who are always vulnerable compared to the well off. Take the case of the recent earthquake in India; in this natural disaster, more than 10,000 people died compared to only a few in the earthquake of similar intensity in California.⁴ In essence, the threshold level to withstand these impacts would be less for developing countries when compared to the developed ones. In such a case, given that the present accumulation of GHG in atmosphere is due to advanced countries, will they be forthcoming to insure the poor against such calamities?

Large scale out-migration from coastal zones is expected due to sea level rise. Intrusion of sea water in the ground water and changes in temperature can reduce agricultural incomes everywhere. This will create a large number of environmental refugees. Will they get migration rights (to the North)? Share of GDP from agriculture in total GDP ranges from 16% to 64% in low income developing countries and 12% to 37% in middle income developing countries compared to only 3% of USA (World development report, 1994). Also, the share of population depending on agriculture are of similar proportions in the south. In short, the impact of climate change will differ from region to region and sector to sector.

While the rich can argue about whether to enjoy more now or pay later in the future and if so what discount rate to use, this is unlikely to be a major issue for the poor who are on the margin of subsistence. If a poor country is forced to reduce their GHG emissions or pushed to adapt to climate change without aid or efficient technology, they would have no option but to reduce their current consumption below subsistence level. Rising concentrations of GHG in atmosphere will bring more constraints on their future development. To conclude, since the poor, wherever they are, have a very high marginal utility of income, if required to curtail their GHG emissions in a comparable way to the rich, the poor will bear a disproportionate burden of global warming caused mainly by the lifestyles and consumption patterns of the rich. Any reasonable decision making framework needs to address this primary

⁴ Of course, two earthquakes are never quite comparable. The point, however, is in the Indian earthquake if only the houses were built with modern construction material, even low cost ones, the loss of life would not have been as much. The people could not afford even such low cost modern housing.

concern. Such a concern automatically raises the issue of equitable distribution which we discuss later.

2.3.2.4 Intergenerational equity and discounting:

Climate change problem will affect many future generations because of long life time of GHG. But, whenever cost benefit analysis is used to evaluate long term benefits and costs, as in the case of global climate change, the practice of discounting the future is severely questioned. One set of critics base their criticism on the belief that discount rates place a low weight on future generations. Another group argues that because discount rates dominate decisions relating to the future, one should use low discount rates whenever one evaluates projects with long term implications. This is the position taken in Cline (1992) when he uses a low discount rate ranging from 0 to 2%.

Ethically, generational welfares are to be treated equally. But, future generations could be better or worse off than the present generation depending on the GDP growth rates. In the former case, if the future benefits outweigh the present abatement costs, one would expect that the future generations should pay for the abatement cost. Such an argument is based on the assumption that in the intergenerational welfare function, atmospheric capital (environment space) is substitutable by man-made capital. This substitutability assumption is highly questionable. If there is no such substitutability between physical and atmospheric capital, one cannot delay abatement actions in favour of setting aside some man-made capital for future generations. Chapter 3 on "Intergenerational equity and discounting" suggests that discounting considerations change if the present generation is richer or poorer compared to the future generation. Most global modelling scenarios (chapter 11 on Integrated Assessment) show that on the average, future generation of South will still be poorer compared to present generation of North even by 2050 or beyond. Thus, global average of all regions can be the reference point for such considerations. Present generation of North could choose discount rate as though global average would be less in future compared to their generation at present, while South can choose discount rate as though the next generation would be richer.

On the other hand, suppose that the future generations are worse off than the present generation. In such a case, what the future would pay for the present abatement will be much less than the cost of abatement. Some argue that intergenerational equity should be dealt with separately as a political decision with ethical dimensions. For a forceful argument of this point

we refer the readers to Schelling (1994), and chapter 3 of this document.

Not doing anything for the benefit of future generation could be acceptable. But, if the present generation is responsible for the losses of the future, as is the case in the climate change problem, then not doing anything is morally unacceptable. That is, not giving them large inheritance is acceptable, but we should not pass on liabilities. Abatement is not to be looked at as an investment option giving returns in the future but as a liability reduction exercise. Hence, the level of abatement of concentrations could be chosen to minimise climatic impacts on poor and then look for the cost effective ways of fulfilling those commitments. Low levels of discounting could play a role in the later step, but, not in the former.

We have described some of the considerations that go into collective decision making. Having collectively decided the concentration levels and interregional responsibilities, individual countries could formulate their strategies to follow respective emission paths. While deciding who needs to do what, one has to take into account various factors such as responsibility interregional equity, North-South transfers and various policy tools to achieve the required emission reductions.

2.3.3 Implications of collective decision making:

2.3.3.1 Cost of delay and slippages (Free riding through delay):

International negotiations are difficult and take long time. Even if the decisions are taken at international level, it cannot be guaranteed that they will be followed up by people at various social strata. Therefore, slippages may occur. However, in the mean time concentrations mount, if no directions are given. A portion of every tonne of GHG emitted occupies some environmental space for about 200 years, which is not available to either future generations everywhere, or constrains the development needs of non-Annex I countries. For example, during the nineties, after signing the FCCC, the Annex I countries would emit about 40 to 50 billion tonnes of CO₂. This could have been sufficient for South to grow and develop for more than 25 years. In addition, high emissions by one party push the other parties either to adapt or to forego their development.

Therefore, if no decisions can be reached soon, at least it should be agreed that Annex I countries would be liable for whatever concentrations emitted after 1990. That is, whatever the outcome of negotiations, it would hold parties accountable for the cumulated emissions

after 1990 which would be retroactively adjusted against their future share, after negotiations are completed. This would prevent free riding and precipitate some action even while matters are being negotiated. While issues such as past concentrations, population can be discussed later, accepting this principle of accountability after 1990 could lead to prudent behaviour and act as some deterrent to all against wasteful consumption.

2.3.3.2 Valuing Common Property (and Paying for It):

The emissions emitted beyond earth's absorption capacity then test the biosphere's adaptation capacity. This capacity to adapt may be also limited i.e., it is an exhaustible resource. How is the atmospheric resource different from many other exhaustible resources we use every day that include metals, and fossil fuels? First of all, these resources have property rights and they are paid for, each time they are used. "Paying for what you use" is a sound economic principle that should be enforced whenever atmosphere is used to prevent misuse. If one does not have to pay for common property, it encourages appropriation of atmospheric capacity. The user charge should be either paid to others when the property also belongs to them or put in a common pool for future use. Second way it is different from other exhaustible resources is that there are substitutes available or likely to be available for them. This is unlikely to be the case for atmosphere of planet earth.

How does one pay for using atmosphere and to whom? Collective decision is required to decide this. How does one value absorption capacity and adaptive capacity? How does one allocate property rights for both? One can think of several ways.

- (a) Consider that those who wish to emit more than their share should pay rent.
- (b) Consider that this is a permanent loss and pay damage costs.
- (c) If and when property rights are allocated, trade or lease them.

2.3.3.3 Accepting Adaptation:

There is ever increasing reference to need for adaptation. Adaptation ranges from switching to different crops, incurring increased cooling costs to migrating or giving up land rights if they are in the coastal areas. Parry & Rosenzweig (1994) have indicated increased hunger in developing countries which is also one way they adapt. That is, due to delay in abatement, global risks are externalised for which there will be no compensation. In any case, adaptation will be too all-pervasive and costs too difficult to isolate for compensation. Will the North pay for dykes in Bangladesh or give migration rights and compensate for shifting and rehabilitation to people from Maldives?

U.S. estimates for costs to build walls along the vulnerable zones to sea level rise is \$130 billion (refer chapter 4). That may be a small share of U.S. GDP, but such measures, even scaling for their coast lines, for say, India, could require very large share of their GDP. Who shall pay India for such a wall? Moreover, one still does not know what would be the environmental impact assessment of such walls. They could also have adverse ecological and economic impacts on coastal zones.

It is said that there may be rise of mean temperature of 0.25 degree per decade. This is sometimes multiplied to get 2.5°C for a century but there could be non-linearity and temperature rise could be more with more GHG accumulations. Moreover, 2.5 degree centigrade mean temperature rise could mean 5.5 degree centigrade rise in the Northern hemisphere due to extensive land areas compared to oceans. Indeed, if this happens, it would be difficult to live in many parts of Indian subcontinent and other populated countries in the mid-east and South Asia and large scale migration may take place. Thus, adaptation costs passed on to others should be internalised in one's actions. It is important to note that marginal damage of one extra degree of temperature is far more serious in the South than in the North, where they may even benefit from that extra degree. Thus, risk tolerance of say, South should matter more than that of North.

Most models developed in the North do not effectively build in the perspectives of the South in adapting to climate change. The resources to adapt often do not exist and the outcome is further human suffering, manifested in, for example, frequent occurrences of the homeless dying from heat stress. South does not have the capacity to adapt except through increased human suffering and is poor enough to have problems of their own. Homeless die of heat stress even today. Finally, adaptation does not solve the problem; it only postpones what more is to

come.

2.3.3.4 North-South transfers:

Several justifications for the North-South transfers are given below. These are not necessarily mutually exclusive. That is, transfers for one may overlap with other. However, these are different ways of looking at North-South transfers¹.

1. Currently there are many countries whose use of environmental space far exceeds their justifiable share of that space. J.Parikh (1993) has indicated that these privileges are worth US \$70. billion per year. Also, North's use of environmental space has a temporal characteristic; that is, these emissions will occupy the environmental space for hundreds of years in the future (Smith, 1991). According to the "polluter pays" principle, those who have occupied this environmental space should pay rent for it for their excess use of the global environment to those whose use is below their entitlements. In addition, when the latter need that space, that should be made available to them. (Rent for environmental space).
2. The consumption patterns of the rich countries have put constraints on the development alternatives of the poor countries. Due to the climate change possibility, the poor will be forced to spend more resources for adapting to the climate change problems; this will constrain the resources available for their immediate development priorities. (Compensation for adaptation burden imposed).
3. Those who have emitted more than their share of the absorption capacity of the atmosphere (in per capita basis) and benefitted, are liable to others for the possible damages arising from global climate change. (Liability payments for damages and excess past concentrations).
4. The cost of delay in emission reduction (by the North) in terms of South's foregone opportunities to development is substantial. This will impose many constraints on the way the South decides on policy options regarding issues such as how to generate power, how to use land, and what crops to grow and so on. Hence, North-South transfers of large amounts are needed to compensate South for the development opportunities foregone. (Lost opportunities due to concentrations after 1990).

As against all these, Global Environment Facility (GEF) gets replenishment of US \$ 2

¹ K. Smith (1991) has used a concept of natural debt to address these issues.

1 billion for three years to address four different global environmental concerns, viz., climate
 2 change, biodiversity, international water, CFC reducing to serve Montreal protocol. One could
 3 also think of North-South transfers through global policy instruments such as tradeable
 4 emission permit regime, joint implementation and so on. We briefly discuss these issues in the
 5 next section. The reader can also see the separate Chapter on policy instruments for more
 6 details.

7 Having discussed considerations for and implications of collective decision making, we
 8 discuss some theoretical considerations involved in making the national and international
 9 decision making in the following section.

10 2.4 PROCESS OF COLLECTIVE DECISION MAKING

11 Let us now turn to the process of climate change decision making. In this section, we will first
 12 provide a summary of steps involved in iterative climate change decision making problem,
 13 criteria for interregional allocation, global policy instruments and consider sequential decision
 14 making procedures.

15 2.4.1 A summary of the steps in iterative decision making:

16 Necessary elements of collective decision making are linked and brought together with
 17 national decision making either directly or preferably through global policy instruments as
 18 shown in figure 2.4.

19 The first step in long-term decision making process is to select concentration level
 20 through collective decision making by considering equity of stakeholders, of those stakeholders
 21 whose emissions so far have not contributed significantly to the current atmospheric
 22 concentration levels. For stabilizing atmospheric concentration of the main greenhouse gas,
 23 namely CO₂, at any level between 350 to 750 ppmv calls for significant reductions in the
 24 emission trends in the near future. Some alternatives are indicated in figure 2.5. If a very low
 25 level is chosen, considerable sacrifice is expected from the present generation. If high level of
 26 concentration is chosen, there would be danger of irreversible damages and high adaptative
 27 costs. Remember that, if 550 ppm is chosen, it is difficult to go back to 440 ppm, but vice
 28 versa is possible.

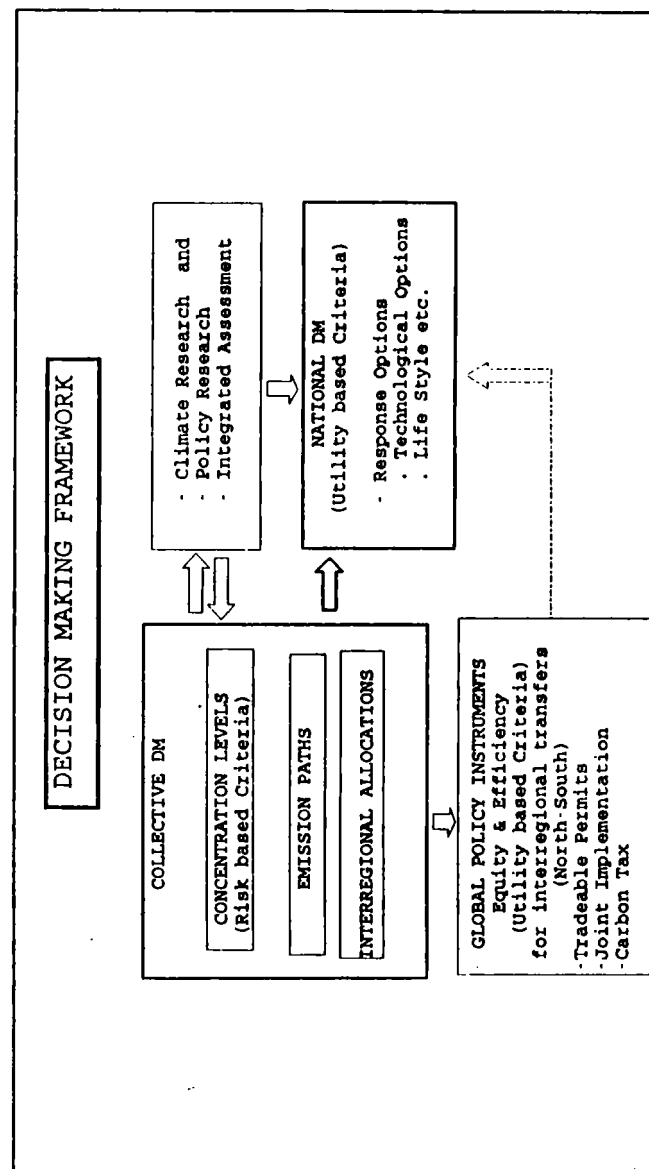


Figure 2.4

1 than north. Emissions per GDP are sometimes taken as indication of inefficiency. However,
 2 high emissions per GDP can be attributed only partially to inefficiencies in South. High
 3 emissions are mainly due to low level of development which requires filling the backlog for
 4 infrastructures such as, schools, hospitals, power plants, due to unsatisfied development needs
 5 such as health, nutrition, education, lighting, and so on where relatively high share of GDP
 6 goes (World Devp. Rep., 1994). This is referred as purchasing power parity. This is
 7 comparable to the fact that, growing children need more food per kg. of body weight than
 8 adults past fifty. Higher need for new infrastructure building explains high emission per GDP
 9 and also calls for higher growth in future. Apart from investment in infrastructure, pricing and
 10 valuation of non-tradeables also matter in these calculations. This can be captured by
 11 adustment factor for purchasing power parity.

12 One could think of a time table in terms of limiting emission by Annex I and non-
 13 Annex I countries through reduction of emission growth rates.

14 Illustration of Strategic Decisions to be taken in Sequence

Time Period	Growth rate of emissions (dC/dt)		Rate of change of growth rate (d^2C/dt^2)	
	Annex I countries	Non-Annex I countries	Annex I countries	Non-Annex I countries
Upto 1990	≥ 0	> 0	≤ 0	> 0
1990-2000	$= 0$	> 0	< 0	> 0
2001-2025	< 0	> 0	< 0	$= 0$
2026-2050	< 0	≥ 0	< 0	< 0
Beyond 2050	< 0	≤ 0	< 0	< 0

15 C : Carbon dioxide emissions

16 This is only an illustration of the process where Annex I Countries take lead and are
 17 followed by non-Annex I countries after some lag. It is a sobering thought that over such a
 18 long period, distinction between Annex I and non-Annex I countries may get blurred and
 19 countries have to be grouped in terms of per capita emissions below and above the world
 20 average.

21 The discussions regarding future entitlements for GHG emission so far have excluded
 22 the historical record of past emissions. Such an omission might be wrong for the following
 23 reason. Increases in the concentration of carbon in the atmosphere have taken place over a
 24 prolonged period of time. The contribution of North America and Western Europe to the
 25 concentration is much greater than their share of current emissions. On the other hand, the

Figure : 2. b
 Annex I : Figure D
 Profiles of Atmospheric CO₂ Concentration
 Leading to Stabilisation at 350, 450, 550, 650 and 750 ppmv

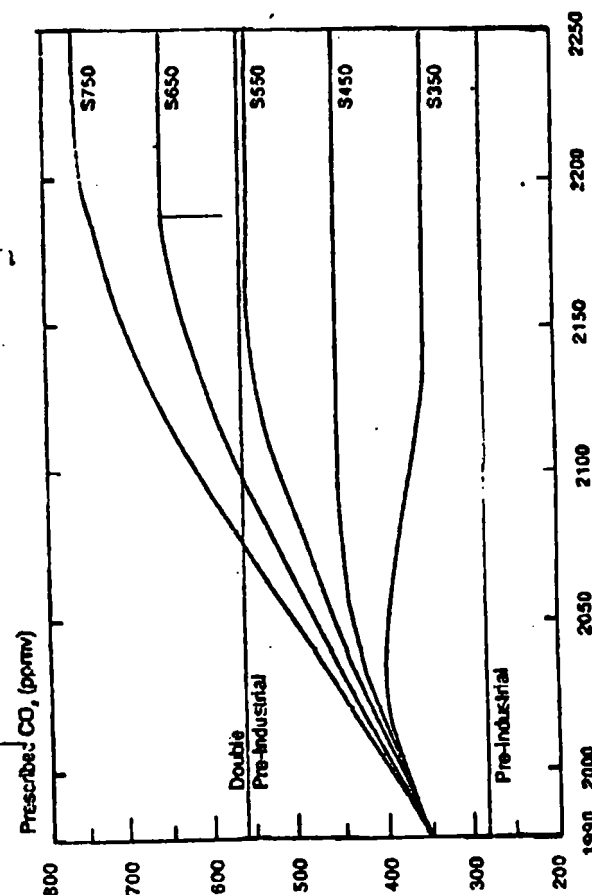
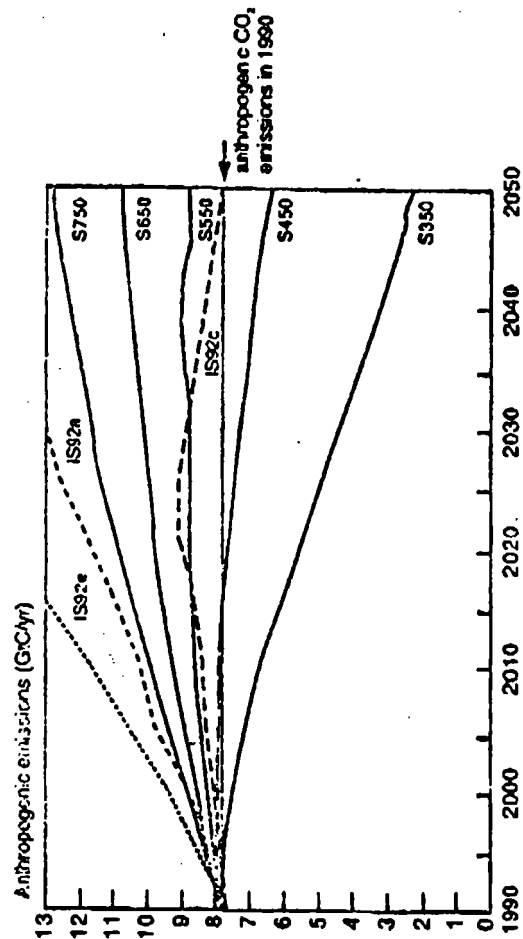


Figure : 2.6

Annex 1: Figure 1

Comparison of IPCC Emissions Scenarios and Emissions Profiles Consistent with Stabilization of Atmospheric Concentrations of 350 to 750 ppmv



historical emissions from developing countries have been low and hence their share of the overall concentration is also low. The current generation of developed countries are the beneficiaries of resource transfers from past generations. These resource transfers have been possible only due to the exploitation of global environmental resources by their past generations. As a result, the current generation living in the developing countries have the right to claim a part of these resource transfers, or, transfer of emission free technologies, or, right to pollute (for development needs), as environmental resources are common property.

2.4.3 North-South Cooperation through Global Policy Instruments:

Once interregional obligations are decided, one could discuss global policy instruments, which make it possible to reduce the cost burden by either trading emissions or by meeting the obligations jointly or by contributing to carbon tax, which can be used to reduce emissions in non-Annex I countries. Global Policy is also needed to discuss ways of North-South transfer, either through the above mentioned or other means. These are referred as global policy instruments. They can be selected based on utility (global or national) based criteria. Institutional failures, such as lack of well defined property rights, and distortionary subsidies, always lead to market failures such as gaps between private and social costs of production and consumption activities. As a result of this, producers and consumers do not appreciate the true scarcity value of the resources they use up, such as environmental resources. The emerging pattern of economic growth from such production and consumption plans is usually unsustainable. Economic instruments which are aimed to correct such unsustainable resource use, bridge the gap between social costs and private costs by internalizing all the external costs and risks. The use of economic instruments at the global level to deal with climate change requires special considerations. We emphasize here these, as they relate to some suggested policy instruments. For a more detailed discussion on the policy instruments, refer chapter 10 of this document.

To elaborate, economic instruments such as property rights, pollution taxes, and tradeable emission permits bring about a realignment of resource allocation with the social objectives. Such economic instruments achieve the objective of sustainable growth through (1) providing a corrective to the functioning of the market, (2) encouraging cost minimization, (3) permitting flexibility of use, and (4) adjustability to changing environment. The key to the promise of economic instruments is their ability to harness the power of the market. Economic instruments can be broadly classified into the following categories: (1) allocation of property

1 rights (ownership rights, use rights and development rights), (2) creating markets (tradeable
2 emission permits, tradeable offsets), (3) economic incentives (emission taxes, subsidies), (4)
3 financial instruments (such as GEF, green fund, location incentives), and (5) liability
4 instruments (liability standards, damage liability, liability insurance).

5 Joint implementation (JI), Tradeable permits and carbon tax are some of the global
6 policy instruments that lead to economic efficiency but require international negotiations.
7 Among these options, JI is already referred in the FCCC and is in the advanced stage of
8 negotiations. Pilot phase of JI is approved by the INC. JI gives opportunity for co-operation
9 between North and South where North can invest in South to reduce GHG emissions, if it is
10 cheaper to do so. South gains in terms of energy efficiency if better technologies are provided.
11 Key question is whether international credit or "offsets" should be given for such efforts. That
12 is, should GHG emissions reduced through JI accrue to the investing country, giving them
13 opportunity to increase their emissions to that extent? If yes, then further negotiations are
14 needed on how much emission reductions through JI can be credited, mode of monitoring and
15 verification.

16 There are concerns that perhaps JI will delay new technology development or
17 consumption patterns of North will not change. Accountability of global GHG emissions when
18 South does not have limits on the emissions is another concern. Therefore, there is no
19 agreement on the credit issue so far. Even if this is undecided, credits or incentives for the JI
20 in the form of carbon tax rebate can be given internally by North. If carbon tax is not imposed
21 by that country government, then it could permit rebate under some other category such as that
22 of treating JI as a category of R&D expense or charity or other tax deductible expenses. Thus,
23 internal incentives can be given to private entrepreneurs by the Governments in the North.
24 Why should the governments in North do so without international credit? JI can have an
25 immense value in terms of capacity building in South, so that when they will have to reduce
26 emissions, they will be ready for it. They may choose to go for energy efficient mode of
27 development. J. Parikh (1994) shows that if South makes some effort to reduce emissions
28 now, it will reduce pressure on North in future as well. Thus, it could have long-term benefits
29 in terms of preparedness of South and reduced global emissions. JI will require monitoring of
30 the projects by certified auditors to account for carbon reduction, especially if international
31 credits are given.

32 Tradeable emission quotas (or permits) is one way of creating a market for GHG

1 emissions. A global level of tolerable emissions is set for greenhouse gases and allocated
2 among the nations by some criteria. Tradeable permits scheme on the other hand, give some
3 developing countries the possibility to earn additional foreign exchange for their development
4 till such time that they have surplus permits. Sooner this is done, earlier the benefits. It will
5 also indirectly encourage them to reduce GHG emissions early, unlike JI, which induces them
6 to reduce directly but sporadically. However, on what basis emission permits should be
7 distributed is a thorny issue about which much is written. Though the desirability of
8 distributing permits (quotas) on per capita basis is recognised at least in the long run (Manne
9 and Richels, 1993), population growth in developing countries is an issue of concern. A
10 compromise could be to have the quotas on the basis of the population fixed in the year in
11 which the agreement is reached. This will encourage North to reach agreement sooner and at
12 the same time South does not profit from population growth.

13 In addition to these options, other forms of co-operation also exist. This could be
14 regional approaches, technology transfer, technology fund or joint technology development.
15 Apart from the North-South co-operation, regional approaches can also be developed keeping
16 in view the common features shared by the regions which may include socio-economic,
17 ecological or meteorological features, viz., temperature, precipitation, solar radiation and so on.

18 Once the goals and policy instruments are agreed upon, national level DM begins. This
19 strategy will depend on utility based criteria or regulatory mechanisms. Their responses will
20 vary from fuel substitutes, life style changes, technological alternatives, or increasing sinks.
21

2.5 Economic Formulation of Individual and Collective Decision Making

"Prior judgements that decision makers bring to the problem, and the decision rules they employ, could be far more important in controlling the policy conclusions that they reach than are the results of scientific discoveries."
Dowlatabadi and Morgan, 1992

This section concerns methodological insights and guidance for making choice between a limited range of actions that have attached consequences, and especially establishing a point of convergence between individual and collective decision making. How we think of choice involves issues of rationality and related decision criteria and rules, and is influenced by various factors among which uncertainty comes first.¹ Whereas a key element of the decision making framework to address climate change is the ratified FCCC (which indicates the objective to achieve, namely, the stabilisation of GHGs concentration), providing a steady economic basis to decision making paths and actions to bring about probably constitutes the most important contribution to the negotiating process.

The long term perspective and the globality of climate changes designate uncertainty as a key factor in decision making. Uncertainty is related both to the science and to the economics of climate change. On the one hand, there is a genuine uncertainty of the climate system—which has bounds but which is not quantifiable (Bolin, 1994). For economics, on the other hand, estimates of the costs and benefits of global warming are much uncertain. In particular, the uncertainty of impacts on individual and social welfare seems predominant.

For example, models in science, in economics and in social sciences provide quantitative estimates of effects based on critically important assumptions that openly leave large band of uncertainty in reference to climate change. Lack of knowledge about fundamental mechanisms that equations cannot currently master represents limits to computer models in each domain. It is also true that most models in the North do not effectively build in the perspective of the South in slowing down or adapting to climate change—both in terms of resources and outcomes.

A priori, however, the existence of uncertainty does not mean inaction. Making decision under uncertainty rather implies to filter paths of action and to choose which strategy with which outcome would be best. This can be done at various analytical levels such as economic rationality, utility-based choice criteria and rules, collective decision procedure (the one FCCC brings forth), short run – long run trade-offs, risk analysis, value of improved information, as well as other particular factors af-

¹ Decision analysis also includes a range of techniques such as cost-benefit analysis or multi-attribute utility analysis. Each tool has a methodological foundation in decision theory but is suitable for different purposes. See 2.4.3.2, below.

fecting decision making; among them one can cite attitude, poverty and intertemporal equity.

2.5.1 Accommodating the supplementary uncertainty caused by climate change

Cognitive and computational limitations make sense with respect to climate change concerns. Decision making is concerned with these limitations.

Indeed, ignoring climate change would simplify decision making. However, it would be irrational to return to our previous lower level of uncertainty awareness. We thus have to accommodate the supplementary uncertainty caused by possible changes in climate (Caselton and Luo, 1994) and their effects on individual and social welfare.

As a consequence of insufficient knowledge and data, predictions of the rate and extent and timing of climate change and their effects have been made in terms of scenarios rather than in usual probabilistic terms. In particular, this situation reflects a gap between the information that is available on climatic processes and the one that would be relevant to Bayesian inference (the common way to use new information to update beliefs "rationally"), and that is in short supply at present time.

What is the issue? In decision theory, decisions are based on the assessment of alternative strategies and the valuation of likely outcomes. The decision process describes uncertainties by means of the concept of "state of nature" (a description of possible "states of the world"—that may be uncertain, as well²). Common decision making is served by the Bayesian approach which represents any information or knowledge concerning states of nature by assigning them probabilities. In this respect, the representation of information in the form of conventional, necessarily precise, probability distributions has been systematically developed in the statistical and economic literature since the 1930s.³

² To formalise the conditions of uncertainty, it is convenient to refer to Arrow's concept of *state of the world* (SOW), a description of the world so complete that, if true and known, the consequences of every action would be known. The meaning of certainty is that the agent *knows* the state of the world while that of uncertainty is that the agent *does not know* the state of the world. Uncertainty characterises all activities; "it affects all fundamental variables that determine behaviour, explain choices and bring about decisions" (Kessler, in Edckhoudt and Collier, 1995).

³ In decision making under uncertainty and risk, the analyst is provided with precise, either objective or subjective probabilities. When it is not possible to arrive at such a unique probability distribution for an event, one tries to construct it from more fundamental events. Such a procedure is known as the Bayes' rule. Suppose the hypothesis B is true and that an event A has occurred. Then, the probability of hypothesis B under the condition that event A has taken place is given by $p(B|A) = p(AB)/p(A)$. $p(B|A)$ is known as the posterior probability and depends upon $p(A)$ which is known as the a priori probability. How do we obtain the prior probabilities? If there are past empirical evidences one can obtain the priors from them. But if there is no evidence available to us about, say, whether global warming or climate change of unacceptable level is going to occur or not, then, according to the "principle of insufficient reason", one has to assign equal prior probabilities to all the mutually exclusive events (or to forget about the Bayes' rule if climate change simply does not allow to make prior probability assessments—Heap et al., 1992). In the first case, if new scientific information is forthcoming, one can use that information to update the prior probabilities or beliefs using the Bayes' rule (or shifts and alternatives to the Bayesian scheme—see below) to get the posteriors. In summary, the Bayesian theory yields instructions on how to use new information to update beliefs "rationally" in certain circumstances. In essence, the Bayesian decision theory is subjective expected utility theory.

In view of the climate change concerns, and lack of knowledge and data, we undoubtedly have to address decision situations that go beyond conventional levels of uncertainty. How to treat information sources (these are diverse with respect to climate change, each of which providing only a small component of the total information—IPCC reports provide the most comprehensive assessment in this field), and how to allow probability assignments to which subsets becomes significant.

2.5.1.1 Strong uncertainty

This means that decision making to address climate change appears as a category of decision making which must envisage shifts to the conventional Bayesian scheme (Caselton and Luo, 1994) when confronting the “strong” uncertainties created by climate change.

“Strong” uncertainty refers to situations where chance is included (which by turn designates common uncertainty and risk), but *knowledge is insufficient*—in other words, situations for which probabilities cannot conventionally be defined.

In short, climate change gives rise to a type of uncertainty that might not be straightforwardly reduced to traditional risk. Phrased in economic terms, technological and economic “common” uncertainties (or, “variability”), while including chance, include the prospect of being pleasantly surprised, whereas climatic and biological uncertainties, while including chance, lie beyond our current cognitive and computational capabilities—and (in as far as they are seen as catastrophes) normally imply a downward trend of expected revenue (Price, 1993).⁴

A more sensible distinction would be between situations in which there is some experimental or observational knowledge on the whole system or parts of the system (i.e., conceivable outcomes would be known, but their probability of occurrence would not), and when there is no such knowledge. In the first case, strong uncertainty can generally be dealt with by assessing “subjective” probabilities to the possible states of the world. In the second case, the situation leads to ignorance.⁵ From a probabilistic standpoint, one can however argue that the distinction between common uncertainty and strong uncertainty (and so between risk and uncertainty as well) is a gradual one, as “objective” probability assessment or statistical inference does not exist.⁶ From such a standpoint, a subjective

⁴ However, this is not the rule for climate change in as far as it might also represent an opportunity, e.g., for innovation, institutional and technological progress; i.e., it can be used positively whether true or not.

⁵ Ignorance basically designates a situation where there is absolutely no information about the unknown state of nature. In the Bayesian theory, ignorance is meant as an informationless prior. Ignorance, and similarly near ignorance, can also be viewed from the perspectives of belief and plausibility.

⁶ The distinction is frequently made between risk and uncertainty on the basis of whether the probabilities are

probability can always be formulated “as a bet on a certain event”. Under these circumstances, the condition for making strong uncertainty computable is that agents at least believe that they know, even approximately, the relative frequencies of the states of the world.

2.5.1.2 Abrupt climate change adds unpredictability to uncertainty and risk

Nevertheless, some controversy exists with respect to probabilities and possible climate changes. On the one hand, the climate change context makes associated risks endogenous (they are affected by our actions) and collective (they are not statistically independent risks) (Chichilnisky and Heal, 1993). For example, circumstances have changed for the insurance industry “in ways that mean traditional practice and the old statistical methodologies are no longer adequate”—“past experience is no longer a safe guide to the far future” (Ayres and Weaver, 1994). On the other hand, strong uncertainty persists with regard to the characteristics of the evolution (rate, abruptness, etc.) of possible climate changes. In sum, climate changes seem to imply a certain degree of irreducible unpredictability beyond the common categories of risk and uncertainty.

On the theoretical side, for example, the important processes influencing the global climate are identified and can be understood at least in principle. Particularly, gases influencing the greenhouse effect are analysed in detail (absorption bands, infrared emissions, diffusion) and so, its anthropogenic modification can be rather exactly calculated. However, the basic assumptions made in such calculations are that the structure of the climate system remains unchanged. Especially, atmospheric and oceanic circulation patterns and cloud formation, in many models, are assumed to remain qualitatively the same, at most being quantitatively slightly affected and so contributing to a positive or negative feedback, amplifying or damping anthropogenic climate effects respectively. Easy to understand, that the prognosticated anthropogenic warming is gradual without discontinuities (+0.3 K per decade).

In contrast to this, the picture drawn by the newest ice core results (Anklin et al., 1993) emphasises variability and instability in a surprisingly unexpected way. Not only does the last ice age show a large number of sharp transitions between a glacial and an interstadial climatic regime (what has been known before) but also reveals the last interglacial age (“Eem”, 125'000 years ago) as being

known/knownable (risk) or not (uncertainty). In this respect, a risk-like uncertainty (knownable probabilities) is sometimes referred to as “weak” uncertainty. There exist more schemes of distinction between risk and uncertainty though differences can rest on science-philosophical grounds (see Vercelli, 1991, Faucheux and Proger, 1994). An alternative is fuzzy logic. The one application of such logic to climate issues is contained in a paper by Leimbach (1993).

1 composed of a series of sharp climatic transitions. The largest uninterrupted interval of *Eem* climate
2 optimum (roughly 2K warmer than our *Holocene* level) encompasses only ca. 2500 years and around
3 20 important abrupt transitions between different climate levels can be observed. The most catas-
4 trophical fluctuation yet analysed happened towards the end of the *Eem*, where the climate changed
5 into a glacial regime *within about 15 years*, to make the same abrupt change back to the original
6 warm climate only 70 years later (Anklin *et al.*, 1993)!

7 The discrepancies between the paleoclimatic observations of abrupt changes and the smooth grad-
8 ual warming prognosticated by today's models could not be more pronounced. They are the result of
9 the fact that the models simulate climate changes as marginal variations around a stable basic climate
10 mode. That the dynamics of this basic mode could dramatically change, being replaced by a different
11 one, is only beginning to be modelled (eg., Manabe and Stouffer, 1993).

12 In the framework of the basic properties of non-linear systems with circular causality, small
13 stochastic fluctuations can become important factors influencing the time evolution of a system. As
14 soon as the system approaches a critical value of a control parameter, an unpredictable fluctuation
15 might be the cause triggering an abrupt phase transition into one of several possible nearby states.
16 Even if all the critical values would be exactly known, neither the transition time nor the follow-up
17 state could be predicted due to the "strong" uncertainty coming from stochastic fluctuations and weak
18 causality. Indeed, the main characteristics of the global climate system is its structure consisting of
19 many interlinked feedback-loops, some of which being highly non-linear. Under these circumstances,
20 the most natural behaviour to be expected is not a gradual warming but rather an abrupt phase change,
21 a transition to another climate regime.

22 It turns out that in addition to the "classical" scenario characterised by gradual warming, two
23 "abrupt change" scenarios can be considered for illustration purposes:

24 • The "*abrupt global change*" scenario, with a sudden important temperature increase within a
25 short period (within a decade), which seems to be a natural candidate based on theoretical reasons as
26 well as new scientific results. The time point where the abrupt change will take place as well as the
27 amplitude of the step and the regional responses will be unknown, so implying "*strong uncertainty*".

28 • The "*abrupt regional change*" scenario with sudden important climate changes in certain re-
29 gions is a possible combination of the above and "classical" scenarios. While the global average tem-
30 perature increase would be rather continuous and reliable, it would be unknown which region will be

1 next for what change. We would thus face a "*globally weak but regionally strong uncertainty*".

2 These perspectives add to the complexity of making decision under uncertainty with respect to
3 climate change. Climate change may be a sudden event. Yet, this does not preclude quantification.

4 In sum, one can argue that although there is some consensus on the ability to deal with uncertainty
5 and risk through subjective probabilities, some uncertainties and risks associated to climate changes
6 may stay outside the reach of traditional practice. Although this is not the right place to expand
7 "classical" and "abrupt change" scenarios, and although probability distributions should not be at-
8 tached to such alternative scenarios, subjective probabilities reflecting low probability but great
9 severity are needed (see 2.5.3.3, below). Alternatively, one must be also aware of low probability
10 outcomes (e.g., in the case GHG emissions would in future be captured). This means that shifts to the
11 Bayesian decision theory must be taken into account. To conclude, Bayesian decision theory has two
12 limitations with respect to climate change: first the existence of strong uncertainties and, second, the
13 existence of low probabilities attached to large potential damages. Indeed, the search for variations as
14 well as alternatives to the Bayesian scheme for reasoning under strong uncertainty has intensified
15 over the past decades to make reliable inference available from unreliable information, vague, partial
16 and contradictory data (see 2.5.3.2 and 2.5.3.3, below). This stresses that, essentially, uncertainties
17 lead to judgement, and that it is the task of political processes to make judgements.

18 2.5.2 "Rationalities"

19 What is choice? On which criteria do individuals make choices in an economic context?
20 Alternatively, do choices with respect to environmental problems convincingly differ from choices in
21 economic situations—which constitute the reference framework in which economic choices apply?

22 The general picture of the *theory of choice* (equivalently, decision making theory) is as follows.
23 The individual can take a *limited range of actions* that have attached consequences. He or she "has in
24 mind an ordering of all possible consequences of actions". Among the actions actually at hand, "that
25 action is chosen whose consequences are preferred to those of any other available action" (Arrow,
26 1951). Such situations constitute the reference framework in which economic choices apply.

27 Central conditions are, for example, a theory of market interactions and clearing as well as any co-
28 herent theory of reactions to the economic stimuli (prices, in essence). Discounting, scarcity of the re-
29 sources, and opportunity costs matter. Assumptions also compose the common economic framework.

1 For instance, a decision-maker's beliefs can always be represented by a unique probability measure;
2 economic agents are said to be perfectly competent to deal with the difficulty of the processes in-
3 volved in the decisional situation. Basically, economic situations (and theory) are based on *the*
4 *consistency of human choice*.

5 Economic criteria of choice primarily rest upon representations and orderings of consequences of
6 actions by means of the assumption of a *utility function*. Such a utility function renders intelligible
7 with regard to observable situations the ability of the consumers to rank their preferences in a
8 consistent order (in like manner, entrepreneurs will prefer more profit to less if each is equally risky).
9 The assumption of a utility function, therefore, postulates a *consistency* of human choice—in short,
10 rationality. This postulate tells the decision-maker that *the focus is on the decision to reach*, not on
11 the process per se. Verily, inasmuch as individuals are assumed to be perfectly knowledgeable and
12 rational, the most valuable option—in terms of utility, or human wishes—is always chosen (Price,
13 1993).⁷

14 *Rationality* and attached utility-based criteria of choice can still play the same pivotal role in
15 climate change-oriented decision making processes as in economic situations.

16 However, decision-makers must initially be aware of the following differences. First, with respect
17 to the climate change perspective, choices are of collective and of longer-term view nature—they are
18 no longer individual and fixed choices (for instance, a country individually cannot take abatement
19 measures in so far as emissions in the rest of the world will affect the country in question and the
20 gains from abatement by this country will accrue to the rest of the world). It turns out that a collective
21 decision procedure, based on a "procedural" kind of rationality, must be set up (see 2.5.4, below).
22 Second, choices are not made with respect to a fixed set of alternatives, either. Third, choices are not
23 confined to market related decision situations, but are also concerned with non-market related
24 decision situations (including issues of poverty or fragility of natural ecosystems and species).

25 2.5.2.1 Utility-based decision criteria

26 Economists do not assert that human agents are "rational" by definition. Rationality is a law-like
27 refutable statement which "simply means behaviour in accordance with some ordering of alternatives

⁷ Simply, it is assumed that in evaluating uncertainty and risk situations, the decision-maker replaces the monetary value of final outcome by the utility (a function) of that one. Therefore, utility can be interpreted as a method "of passing from a more objective level to a more subjective level: that of the amount of satisfaction achieved" (Eeckhoudt and Gollier, 1995).

1 in terms of relative desirability" (Arrow, 1951, Blaug, 1992). It designates a "*maximization of the ex-*
2 *pected value of a given utility function*" (Savage, 1954; Arrow, 1987).

3 Subjective arguments are compatible components of the assumption of a consistent utility-max-
4 imising behaviour. Expected utility (together with the notion of expected value, the return) is the
5 prime economic criterion for choice. It can take account for risk through various utility-based criteria.

6 *Utility-based criteria* mean addressing the maximisation of expected utility (or value—cf. Box
7 2.5–I). They entail decisions that are based on the valuation of outcomes—wealth levels, time streams
8 of consumption, etc.—(Morgan and Henrion, 1990).

Box 2.5–I: Examples of some utility-based decision criteria
Source: After Morgan and Henrion, 1990: 26

<i>Benefit-cost:</i>	Estimate the benefits and costs of the alternatives in economic terms and choose the one with the highest net benefit.
<i>Maximise multi-attribute utility:</i>	This is the most general form of utility-based criterion. Rather than use monetary value as the evaluation measure, MAU involves specifying a utility function that evaluates outcomes in terms of all their important attributes (including uncertainties and risks). The alternative with maximum utility is selected.
<i>Cost effectiveness:</i>	Select a desired performance level, perhaps on non economic grounds. Then choose the option that achieves the desired level at the lowest cost.
<i>Minimise chance of worst possible outcome</i> <i>Maximise chance of best possible outcome:</i>	Political and behavioural considerations frequently dictate the use of such criteria.
<i>Maximum budget (bounded cost criterion):</i>	Set the maximum budget to devote to risk management activity.
<i>Minimise maximum regrets:</i>	Choose measures of "regret" and minimise the maximum regret.
<i>Minimax Loss (Minimax criterion for catastrophic risk):</i>	For each decision alternative find the loss associated with the extreme event. From among these losses find one with the maximum loss and try to minimise it. This is a conservative criterion.
<i>Maximin Gain:</i>	Find the gains associated with each action and try to maximise the minimum of these gains.

10 For example, if the climate damage is sufficiently great, or the uncertainty of such effect suffi-
11 ciently strong, it will even pay a poor country to adapt or contribute to slowing down climate change,
12 even at a low level of income. Poor countries have invested heavily in industrial and irrigation pro-
13 jects, thereby sacrificing present consumption to seek higher incomes in the future. In some countries,
14 such as Singapore, people have voluntarily engaged in high savings (45% of income approximately)

even at low present consumption levels to achieve a better life in the future.

The implicit argument is a redistributionist argument based on the higher marginal utility of income at lower levels.

2.5.2.2 Bounded rationality

Rational behaviour is a "first approximation" to actual behaviour. Indeed, as soon as one faces either imperfect forms of competition or non-market resources allocation decisions, knowledge requirements radically shift and exceed those usually required for a pure market framework. In addition, there might be as many rationalities as there are cultures.

It is anyhow widely accepted that (economic) rationality hypotheses be supplemented by assumptions of a different character (e.g., information-gathering ability and limitation of both knowledge and computational capacity). It is accepted that rationality, obviously, is *bounded* (Simon, 1957, Arrow, 1987). In principle, these cognitive difficulties are connected to decisions that lie beyond individual-related, common economic situations; they relate to decisions that must be reached through *international conventions*, or to decisions that, *independently of the valuation of the outcomes*, are destined to eliminate risks.

As a concept, "bounded rationality" has been coined to name rational choice that takes into account the "cognitive limitations of the decision-maker" (Simon, 1987). Basically, this tells the decision-makers that rationality can be also concerned with *the ways in which the actual decision-making process influences the decisions that are reached* and not only with reaching decisions assuming the maximisation of expected utility, as we are used to consider from a common economic viewpoint.

This concept thus designates a different type of rationality, namely procedural rationality. Incidentally, a decision which optimises co-operation will possibly be in opposition with a decision which optimises the expected value of utility because the latter places the focus on *the decision to reach* while the former places the emphasis on *the decision process in itself*.

2.5.2.3 Procedural rationality

The former cognitive limitations may break usual limits on specific information. In the words of Simon, they are almost always limits on the adequacy of the scientific theories that can be used to predict the relevant phenomena (Simon, 1987). Meteorology and atmospheric chemistry, on the one hand, as well as economics, on the other hand, openly leave large bands of uncertainty in reference to

climate change. In addition, lack of knowledge about fundamental mechanisms that equations cannot currently master represents limits to computer models in both domains. These difficulties typically occur with respect to decisions that are taken on a national or international scale *when governments negotiate some form of agreement and countries differ in their economic wealth, reliance on fossil fuels, endowment of alternative resources and technical capabilities*.

Specifically, "procedural" rationality designates the rationality of a decision in terms of the *manner in which it is made* while economic rationality names the *rationality of a decision considered independently of the manner in which it is made* (in the case for economic—equivalently, substantive—rationality, rationality evaluation refers exclusively to the results of the choice, not to the decision-making process in itself—Faucheux and Froger, 1994).

Which kind of theory can better support and explain the decisions at issue under FCCC? Shall we place interest in the decisions to be reached only, or shall we focus attention on the (International) decision procedure as such? Answering to these questions and the like would command the choice between economic and procedural rationality frameworks (Simon, 1987). From an economic standpoint, unfortunately, the fact that the manner in which the decision is made—and not the result of the choice—is at issue in the decision evaluation makes the procedural kind of rationality mostly undetermined. This tells decision-makers that procedural rationality should be bounded to the processes of collective decision making, i.e., the steps in negotiating treaties and agreements. We will return to this in subsection 2.5.4., below.

2.5.3 Responses to uncertainty and risk

Getting back to the distinction between uncertainty and risk made on the basis of whether the probabilities are not (uncertainty) or are known/knowable (risk), let's consider how (intuitively) to proceed.

The classical ingredients of a decision problem under uncertainty are a set of feasible acts (A), a set of consequences (C), and a set of states of nature (S). The decision-maker does not know for sure which consequence will result from a chosen act (*probabilities for the events are not known in advance*). The role of the states of nature is to indicate the matching of feasible acts to consequences, thus resolving the uncertainty which relates acts to consequences. This makes states of nature exogenous (uncertainty becomes in like manner exogenous, too) so that probabilities can be computed. As a result, the decision-makers basically have to assign utilities to the consequences (utility U assigned

to each consequence c in C and probabilities to the states (probability p assigned to each state s in S) (Schmeidler and Wakker, 1987).⁸ In choosing between acts, the decision-makers will elect that one with the highest "expected utility" (or, expected value)—that is, the one with the highest sum of the products of probability and utility.

A decision making under risk introduces a special formulation of the decision problem to the extent that probabilities for the events are known in advance. In other words, the decision problem includes the probability distribution of an act over the consequences. Accordingly, decision-makers only have to determine utilities of consequences before choosing between acts.

Yet, this presentation reflects individual election and addresses common economic or technological variability; it is not straightforwardly designed to address unpredictability and judge risks like those climatic and biological possible catastrophes might imply (see 2.5.3.3, below). As a first rough approximation with respect to climate change, the expected utility criterion says that it is possible to retain the notion of expected value (the return) while, with reference to uncertainty decision rules (see below) and efficient risk sharing (see 2.5.2), also taking risk into account.

2.5.3.1 Uncertainty and risk decision rules

One can move from the pure decision criteria that appear in Box 2.5–1 to more simple decision rules; i.e., rules which do not need to elucidate all possible outcomes and their respective probabilities.

First, approved individual/collective decision rules with respect to uncertainty can be outlined as follows (MIT, 1986):

Maximax	The decision maker should opt for that course of action which yields the highest pay-off (net benefits, or whatever) regardless of any view taken about which state of nature will occur. It's the optimistic rule.
Maximin (Wald, 1950)	...We should first observe all the minimum pay-offs and then select the highest of these. Amounts to expecting the worst (Price, 1993)—presumably in our case, the failure of technology or substitution to relieve climate change constraints. Decision-makers who employ this criterion are extreme pessimists.

⁸ A specific way allowing to cover the case for uncertainty—originally about the availability of resources and about consumption and production possibilities—is the idea of *contingent commodity* introduced by Arrow (1953) and developed by Debreu (1953). This device is added to the current specifications of the commodity such as its physical characteristics and location to make the availability of the commodity contingent on the occurrence of some (uncertain) environmental event such as weather conditions.

Minimax (Savage, 1951)	...We should select measures of "regret" (i.e., the difference between an actual pay-off and what the pay-off would have been if the correct strategy had been chosen). This is a cautious principle and ensures that, if the worst happens, we make "the best of a bad job". Emphasises the cost of making the wrong decision (Price, 1993). ...We should seek to minimise the maximum regrets. ...We should seek to minimise maximum loss (Dowlatabadi and Morgan, 1992).
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Second, basic individual/collective preferences towards risk can be outlined as follows:

Risk aversion:	Higher expected return is needed as compensation for an increase in risk. A risk averter can be a diversifier and spread his <i>portfolio</i> over different assets—or a "plunger" and invest wholly in bonds and money.
Diversifier:	Risk is likely to be the cause of <i>portfolio</i> diversification: if risks increase then the diversifiers will move back to holding wealth in the form of money.
Risk lover:	A risk lover accepts a higher level of risk for a given expected return.
Risk neutral:	A risk neutral individual would be indifferent whether or not he or she accepted "fair" insurance. Under risk neutrality, the risk premium is zero.
Cautiousness:	Defined as decreasing risk aversion (Pratt, 1995). The cautious person has no dislike for uncertainty as such, but feels that he or she "can expect to do better in the long run by playing it safe for the present and thus increasing probability that he/she will have the funds available to take advantage of more favorable deals which may arise in the future (Schlaifer, 1961; after Pratt, 1995). Cautiousness is thus derived from risk aversion.

2.5.3.2 Decision analysis techniques

Application of utility-based criteria and rules involve a full range of techniques, each of them being suitable for different purposes. Some are designed to serve as an aid to collective decision making.

One is a balancing of benefits and costs in a Benefit-cost analysis framework. Game theory is one another. Techniques developed by management scientists over the last 10-20 years (which are sometimes collectively referred to as "Soft System Analysis" and include Strategic choice analysis, Robustness analysis, Hypergame theory and a number of others) are other ones (cf. Ríos, 1994). One another grouping of methods for reasoning under uncertainty is Evidence Theory, or defeasible reasoning and uncertainty management techniques (Kohlas et al., 1994). This group concerns the

1 study of symbolic and numerical methods for the representation and management of incomplete
2 information. Basic research activities cover domains like nonmonotonic logics, fuzzy logic and
3 possibility theory, "surprise" (Shackle, 1967), "imprecise" probability (Walley, 1991), Bayesian net-
4 works, Dempster-Shafer theory of evidence (Dempster, 1967, Shafer, 1976; Caselton and Luo, 1994)
5 and "Non-expected utility models" (Yaari, 1987). It attacks, notably, problems related to uncertain,
6 unreliable, vague, partial and contradictory data.⁹

7 A different conception is the Multi-attribute utility analysis which is suitable for situations where
8 options involve "collections of attributes that are incommensurate" (Keeney and Raiffa, 1976,
9 Morgan and Henrion, 1990). The resulting decision model can avoid the dilemma of converting each
10 attribute to an equivalent monetary value.

11 Variations to utility-based decision criteria are available. A Cost effectiveness criterion can be
12 used where the value of benefits cannot be estimated—but a choice must be made between alterna-
13 tives (Morgan and Henrion, 1990). A Maximum budget can be set to devote to risk management ac-
14 tivity (bounded cost criterion). Last, measures of "regret" can be chosen and the maximum regrets
15 minimised.

16 Other methods or tools are thought to help diagnose the *negotiation process* itself, for example,
17 Cognitive mapping, Simulation modelling, Rule-based systems, an Information management (IIASA,
18 1993). Techniques belonging to decision analysis can be reoriented to serve as negotiations supports
19 as well. One can cite Cross-impact analysis that facilitates the modelling of complex situations or
20 stakeholder analysis which uses information on the position, interest, priorities, and preferences of
21 various stakeholders on a particular issue to facilitate analysis of the range of differences among
22 stakeholders and the potential for coalition formation (IIASA, 1993). Multi-attribute utility analysis
23 techniques have been applied by researchers at IIASA to evaluate coalition building and preference
24 adjustment in the UN Conference on Environment and Development.

25 2.5.3.3 Addressing strong uncertainty

26 Under climate changes situations, decision-makers need to pay attention to situations of strong uncer-

⁹ An essential aspect of a decision analysis is the ability to combine information from various independent sources. For instance, in the Dempster-Shafer context, if two basic probability assignments (BPA) on the same unknown state of nature are obtained from two different independent sources of information, they can be combined to yield a new resultant BPA. This kind of scheme also allows at specifying probabilities on intervals of the state of nature, leading to a possibilistic specification of probability.

1 tainty, which in this matter might not be exactly an exceptional situation but maybe the rule. In this
2 context, one may choose two different ways.

3 First, as regards *strong uncertainty*, the approach based on the exploration of the future on the ba-
4 sis of the use of scenarios appears as one of the few relatively-useful instruments. This can address
5 mitigation and adaptation to climate changes, the phasing out existing policies, as well as climate and
6 technology research.

7 Second, in so far as climate change risks can be delineated, the risk assessment of potential cli-
8 mate change can deliver probability distributions of the different estimates to policy makers (see
9 Chapter 7, below). On the other hand, in so far as we accept to bet on future events according to a set
10 of possible descriptions of collective risk, it could be natural to allow agents to *trade securities*
11 *insurance contracts* (see 2.5.2, below).

12 In sum, an open question is: *are policy makers better served by best guess scenarios than by prob-*
13 *ability distributions of these estimates* (Shlyakhter *et al.*, 1995)?

14 These options can be reconciled by drawing distinctions between scenarios that are *probable* (risk
15 situations) and those that are *possible* (strong uncertainty situations). According to Shlyakhter *et al.*
16 (1995), *those risks that fall below a particular threshold of probability*—and thereby are ignored by a
17 particular group or society—are called "*de minimis*" risks. "How societies and governments decide
18 what constitutes *de minimis* risk in particular situations or contexts is largely a matter of political
19 judgement" (Shlyakhter *et al.*, 1995). Although there is no clear definition of a *de minimis* risk, it can
20 generally be seen to be closely akin to a related concept, namely, the *probability of "surprise"*.

21 The next question is: "At what probability of a serious effect should society take action?" How to
22 compute a *de minimis* risk—equivalently, a probability of surprise? Although many conceptions and
23 definitions are possible, the use by Shlyakhter *et al.* (1995) of the word *surprise* is meant to denote
24 those situations where the true values of a particular uncertain parameter, e.g., climate sensitivity to
25 CO₂ doubling, appear at least 2.6 standard deviations away from its current "best guess" value. For a
26 random variable that is assumed to be normally distributed, the probability that the "true" value is
27 more than 2.6 standard deviations from the current «best guess» is just 1 percent. As Shlyakhter *et al.*
28 (1995) continue, it is interesting to note that public opinion polls suggest that many people are uncon-
29 cerned about a 5 percent chance of a climate-related catastrophe within their lifetime, although they
30 are concerned about a 1 percent chance of a nuclear accident. They also note that an airliner with a

1 calculated chance of failure around 5 percent in its 70 year life would not be allowed to fly in commercial service.

2 Last, qualitative and probabilistic changes relate to the expected value of a single experience. As
3 such, they have "close affinities with the meaning of discounting" (Price, 1993; also cf. Chapter 3).

4 2.5.4 Collective decision making

5 To discuss the choices of a group rather than of an individual, one can use an index of social welfare
6 as a "utility" function. This fits into the framework of maximising the expected value of a function.
7 The group then makes collective risky investment decisions and insurance decisions by using this
8 function. Though collective decision making is central in economic analysis, many applications are
9 analysed in this way; that is, using microeconomic analogies and inferences.

10 Specifically, however, a group has possibilities of risk retention that are much greater than that of
11 an individual. "This is partly due to the opportunities of diversification within the group and partly
12 due to the transfer of risk towards the least risk-adverse members (or the richest members if absolute
13 risk aversion is decreasing)" (Eeckhoudt and Gollier, 1995). This is why organisations have always
14 been best suited to undertake risky activities—adapting to or slowing down climate changes is a risky
15 activity by itself due to the existence of strong uncertainties. "Without this diminution of risk
16 aversion in an economy, thanks to the creation of risk pools, many risky projects would not have been
17 undertaken and we would undoubtedly not have known the economic expansion that we have
18 observed over the last two centuries" (Ibid.). In practice and with respect to climate change,
19 applications of collective decision making regard two out of three key rationales this chapter will
20 select: *insurance* decisions (2.5.2) and a policy measures *portfolio* (2.5.3) (the first rationale is time-
21 oriented, i.e., *sequential decision making paths*—see 2.5.1).

22 Specifically again, 'collective' decision making means the choice of weights for the members of the
23 group. For this reason, the valuation of outcomes will become matter of negotiation under a collective
24 decision making framework. Yet, negotiation proceeds along a particular procedural scheme, to
25 which we turn now.

26 As a procedure, collective decision making concerns the processes of co-ordinated decision-
27 making, i.e., the steps in *negotiating* international treaties and agreements, the appropriate weights,
28 decision criteria and/or rules if any, and the particular decision procedure. In this context, 'collective'

1 decision making should read intergovernmental "*negotiated*" decision making.¹⁰

2 2.5.4.1 Steps in negotiating international environmental treaties and agreements

3 Environmental accords tend to be partial and incremental. On the one hand, they tend to be integrated,
4 complex packages of multiple linked issues that are difficult to negotiate internationally. On
5 the other hand, they are made of several steps such as pre-negotiation, negotiation and post-negotiation
6 processes. This is due largely to scientific uncertainty concerning the problems and possible
7 solutions, and the (a priori) need for continued learning about effects and consequences. Partial
8 agreements are also customary because of the political uncertainty in devising fair and equitable approaches
9 at a global level (IIASA, 1993).

10 Sustained negotiation or post-agreement negotiation are also an attribute of current international
11 environmental negotiations. This is the case, namely, for the UN FCCC, its former Intergovernmental
12 Negotiating Committee (INC) and its new Conference of the Parties (CoP). Post-agreement negotiation
13 can be defined as the dynamic and co-operative systems, procedures, and structures which are institutionalised
14 to sustain dialogue on issues that cannot, by their nature, be resolved by a single agreement.
15 A framework convention or a protocol mechanism often have no clear end-point. A broad framework
16 of principles is agreed to first, followed by additional talks to specify details (IIASA, 1993).

17 Procedural issues need to be addressed further. It results from a study by IIASA (Sjöstedt, 1993)
18 that the following ones need to be dealt with by practitioners and researchers alike:

- 19 • Many new groups and individuals beyond traditional governmental officials are now important
20 participants in the negotiation process.
- 21 • The complexity of international environmental negotiations is increasing. Policy makers have
22 linked environmental issues with other important policy concerns, such as development and
23 trade. The implications of these linkages are often not well understood. Ways must be found to
24 develop a common understanding of these linkages.
- 25 • Bridging the differences between industrialised and developing countries will be a continuing
26 problem, given their different interpretations of what constitutes fair and equitable solutions.
- 27 • New approaches to innovative problem solving need to be found and implemented, perhaps
28 using the assistance of third parties or creative reasoning heuristics.
- 29 • New strategies to implement negotiated environmental agreements are needed to reduce
30 national ratification delays and increase the likelihood of compliance (IIASA, 1993).

¹⁰ The choice of the country as decision unit has formal justification in international law. However, this does not solve real world decision making in as far as major energy producers and users are directly involved in it. Therefore the paramount importance of utility-based decision making criteria and rules.

1 Unlike the processes of pre-negotiation and negotiation, post-agreement negotiation has received
2 little attention from researchers in terms of their procedural rationality. Options can be:

- 3 • Involving domestic stakeholders in negotiations from the beginning.
- 4 • Modifying the structure of the accords themselves: Clusters of simple, single-issue agreements
5 may be more practical.
- 6 • Initiating a new learning process in the post-agreement negotiation process in as far as
7 international problems can be more abstract than local environmental issues.

8 Post-agreement negotiations present policy makers with the challenge of progressively reframing
9 problems, adjusting strategies and perceptions, and refining solutions (IIASA, 1993).

10 2.5.4.2 Collective decision criteria

11 At the world level, decisions cannot be easily based on individual-like utility functions (index of
12 social welfare). In addition, once it is accepted that we have no world sovereignty and no global
13 social welfare function, *the outcome is a matter of negotiation*. This is the way to address the choice
14 of weights for the members of the group.

15 How much each country has to say is, however, more a matter of what is than a matter of ethics.
16 The literature on negotiation analysis (Fisher and Ury, 1981; Raiffa, 1982; and others) stresses that
17 each party to an agreement must find himself better off with the agreement, than without. Otherwise
18 he has no reason to agree.

19 The Conference of the Parties (CoP) will be the apex forum which makes the collective global en-
20 vironmental decisions for global welfare within the constraints set by environmental risk and eco-
21 nomic efficiency.

22 One possibility is to use *collective decision criteria* (or, rights-based criteria).

23 One another possibility is—in as far as every country has its predispositions in the debate, and
24 there can be no certainty about which position will be vindicated in the passing of time (Price,
25 1993)—to adopt *traditional criteria for decision making under uncertainty*.

26 The maximin criterion (Wald, 1950; see also 2.5.3.1, above) amounts to expecting the worst—
27 presumably the failure of energy and technology substitution to relieve climate change constraints—
28 and adopting a policy based on that expectation (Price, 1993).

29 The minimax regret criterion (Savage, 1951; also see 2.5.3.1) emphasises the cost of making the
30 wrong decision—presumably, in the climate change context, the very high cost of damages as a result

1 of assuming technological progress which might fail to materialise.¹¹

2 *Convention-related principles* are still one another possibility. Indeed, the need for an equitable
3 distribution of tasks both at the national and international levels is the cornerstone of the Framework
4 Convention on Climate Change (FCCC). For example, while all the Parties are required to contribute
5 to the collective effort by elaborating a national programme, the application of *the principle of*
6 *"common but differentiated responsibilities"* implies that the industrialised nations should take
7 *strong measures*—first by adopting specific national measures to stabilise greenhouse gas emissions,
8 second by promoting the transfer of financial resources, know-how and/or technologies to developing
9 countries, in particular the least developed countries (FCCC, 1992, BUWAL, 1994).

10 The precautionary principle also belong to the FCCC-related principles. Basically, it is a rights-
11 based criterion. According to FCCC, however, it has been thought to encourage nations and individu-
12 als to take early actions to prevent environmental damage even when these actions are not
13 "economically attractive". In this sense, it might look like some *legal or ethical principle*, and
14 consequently be in contradiction with cost-effectiveness demands (that also are requested by the
15 framework convention on climate change!).

16 2.5.4.3 Decision procedure

17 The Convention establishes flexible procedures, based on the submission by governments of national
18 communications, in order to ensure that States implement their commitments. These procedures are

¹¹ Here are examples of some collective, rights-based criteria (Morgan and Henrion, 1990):

Zero risk:	Independent of the benefits and costs, and of how big the risks are, eliminate the risks, or do not allow their introduction.
Bounded or constrained risk:	Independent of the costs and benefits, constrain the level of risk so that it does not exceed a specific level or, more generally, so that it meets a set of specified criteria.
Approval/compensation:	Allow risks to be imposed only on people who have voluntarily given consent, perhaps after compensation.
Approved process:	Not strictly a decision criterion for analysis, but widely applied in risk management decision making. If all relevant parties observe a specified set of procedures (e.g., under some international convention), then any decision reached will by definition be acceptable.
Liability insurance:	Parties which impose risk might be eligible for liability insurance (added example).

Rights-based criteria have been thought to deal with processes and constrained actions or activities (Morgan and Henrion, 1990). For instance, the *approved process* criterion insists "that all the relevant parties observe a specified set of procedures" such as some internationally signed convention defining a due process (this leads us back to procedural rationality). Some of these criteria are *inconsistent to deal with exogenous, naturally occurring risks* as for instance the *zero risk* criterion which simply does not allow the introduction of the risk. Hybrids of utility- and rights-based criteria are some times used.

also designed to allow if necessary to amend the Convention in the light of new knowledge, for example through protocols dealing with specific areas (BUWAL, 1994).

In line with the provisions of the FCCC (Art. 4.2e), industrialised countries must also co-ordinate economic and administrative instruments. International co-ordination also helps at avoiding undesirable side-effects such as trade distortions and unwanted impacts on the environment of third countries.

All countries should participate collectively in efforts aimed at solving global environmental problems, based on an equitable sharing of responsibilities. In this respect, increased solidarity between the planet's rich and poor regions is essential.¹² Attention should also be paid to providing financial support to the Central and eastern European nations, in order to encourage their full participation in the work undertaken within the FCCC.

Under FCCC, indeed, the developing countries have no obligation to control emissions and therefore do not need to pay "global carbon taxes". However, if a CO₂ tax is imposed, *efficiency requires that it be imposed on everyone*. Energy efficiency is just as important in poor countries as in rich countries. The issue is exceptionally sagacious: (a) Equity may demand that the proceeds of the tax be remitted to the developing countries; (b) however, there seems to be no objections raised against tradable permits; (c) as a rule, transferable permits *amount to a tax on emissions by all countries*.

For example, if India or any other developing country seeks to increase its own combustion, it reduces its sale of permits to the developed countries and therefore loses that revenue; this is equivalent to a tax.¹³

It turns out that *all* countries have to reduce their emissions, at least compared with what they otherwise would do. The growth of non-Annex I countries depends *both* on emission reductions in Annex I countries and on increased efficiency in their own energy usage. Developing countries should not be exempted from the tax—as this would lead to inefficiencies.¹⁴ Instead, they could be

¹² This argument does not imply that poor countries cannot afford to take any thought for the future. They do, and have to do, though day-to-day adversity can become pervasive, as it is the case in large parts of Africa. This does not mean that there is nothing for Northern parties to gain from an agreement, either: a growing prosperous South contributes to the North through international trade and reduces the possibility of environmental refugees and northward migration pressure in general; Northern countries do have moral and humanitarian interests in reducing poverty of some countries; though smaller than likely Southern adverse impacts, there are adverse impacts that the North will suffer too; last, we all have interest in avoiding an irreversible catastrophe.

¹³ This example also concerns the problem of decision making at the firm or at the household level (Chapter 8 deals with the process of innovation and technology adaptation by firms and households—see 8.3.1.3).

¹⁴ In addition, one of the major thrusts of environmental economics is that society must internalise the costs of "free" natural resources (the atmosphere). This obligation applies to developing and developed countries alike. The carbon tax is

entitled to an overproportional share of tax recycling. In this respect, however, liability would be impossible for emissions prior to the discovery of the possibility of anthropogenic warming (ca. 1988). Instead, it should be recognised that more GHG efficient technologies are available to developing countries than it was the case when developed countries were in development phase, and that the only path to development is not the one that has been travelled by developed countries (otherwise, it must be acknowledged that developing countries will be the source of most pollution in future years).

In this respect, joint implementation (JI) can be a valuable instrument though controversies—that mainly are political and not economic—still surround the concept. Used in very flexible manner, it would induce additional transfers to the South. Developing countries would not invest in "climate change abatement" but might change their development strategy in ways that are compatible with lower GHG emissions. Left without efficient devices then the South is unlikely to invest in abatement of climate change. This will have to come from the North. Second is cost-effectiveness. Any Northern investment in abatement would be most cost-effective through joint implementation (Chapter 4; Pillet et al., 1993). Last, it now clearly appears to many developing countries that solving the climate change issue is closely linked to future development paths (Villanuova, 1994). So it is in the global interest that North South trade reliable, cost-effective mitigation.

2.6 A Sequential Decision Making Framework to Hedge Against Impacts of Uncertainty and Change

This section concerns the decision making framework for hedging against possible climate changes and related impacts, and especially establishing decision making paths relative to uncertainty and risk, exploring the use of financial markets, and pooling different kinds of policy options.

2.6.1 Decision making paths: Which strategy would be best?

2.6.1.1 Scenario analysis

The decision making framework to address climate change is served by scenario analysis. Scenario analysis is one of the few relatively-useful instruments at hand to look at the here-and-now significance of alternative futures. Uncertainty is indirectly treated; that is, the very existence of uncertainty makes alternative scenarios different, but uncertainty is not incorporated within scenarios one means of doing this.

1 Within scenarios, therefore, the analysis proceeds as if we definitely had the opportunity to learn the
 2 state of the world before taking action—in other words, it proceeds as if all uncertainties are resolved
 3 prior to the date at which decisions are taken. Each scenario develops within a certainty-like context.

4 A decision-making framework is made of a combination of paths that lead to a decision making
 5 strategy. Scenarios are no decision-making paths. Acting is a path. Learning is one another path. The
 6 best combination of such paths would give the best strategy.

7 The size of the strategy will depend on the probabilities assigned to alternative outcomes attached
 8 to possible states of the world (which can be served by alternative scenarios). The value of improved
 9 information (expected value of perfect information) will play a central role.

10 2.6.1.2 Sequential decision making

11 Alternative combinations of decision-making paths give alternative characterisations of the decision
 12 problem.

13 One strategy is to proceed as if we definitely had the opportunity to learn the state of the world
 14 before taking action; in other words, as if all uncertainties were resolved prior to the date at which
 15 decisions will be taken. This decision making strategy can be called a “learn-then act” strategy.
 16 Learning comes first. Then, once all uncertainties are more or less resolved, action can be taken.

17 One another strategy is to hedge against the probability of surprise such as those risks that fall
 18 below a particular threshold of probability. Such a strategy can be sequential, proceeding under an
 19 “act-then learn” characterisation of the decision problem: decisions are taken (acting) for the years to
 20 come without knowing which of the possible states of the world will occur in a sequence of decisions
 21 allowing new information (learning) to be incorporated into a complex decision process.¹⁵

22 See Figure 2.6—1(a) on which a circle denotes a chance, and a square a decision node.

23 To illustrate, Box 2.6–I shows hypothetical emissions constraints ascribed to each of the three
 24 states of the world under the “learn-then act” procedure (Fig. 2.6–1a).

25 Figure 2.6–1 shows the decision trees:

26 (a) for a “learn-then act” decision strategy (learning about damage potential, then acting) and

27 (b) for an “act-then learn” decision strategy (hedging against damage potential by acting first, then
 28 learning about the damage potential, and then acting again).

¹⁵ Hedging is not equal to “act-then learn” as learning does not necessarily take place.

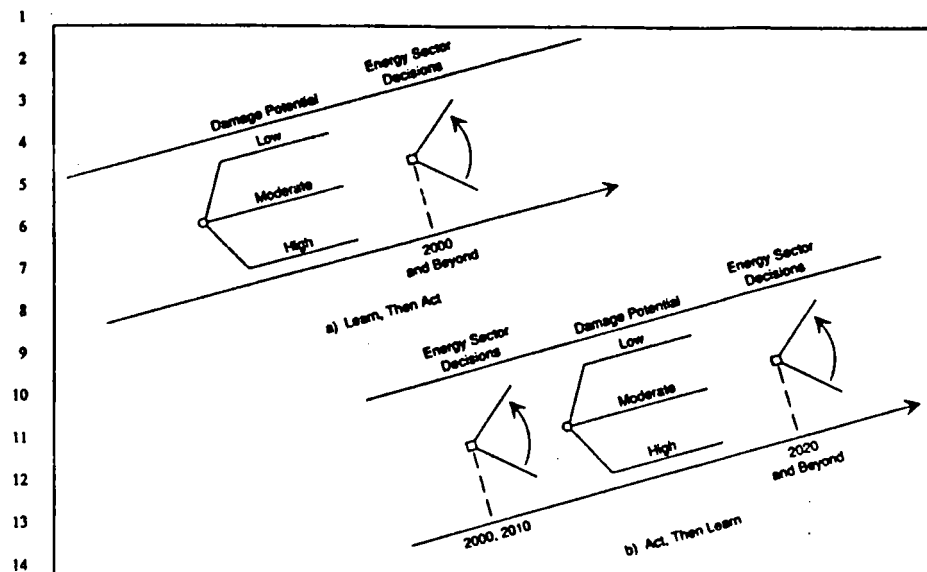


Figure 2.6–1: Alternative decision making strategies
 A circle denotes a chance node—a point at which an uncertainty is resolved.
 A square denotes a decision node—a point at which actions are required.
 Manne and Richels (1992).

Box 2.6–I: Emissions level under “learn-then act” procedure (hypothetical)	
Damage potential	Carbon emissions (2010 target)
Low	Unlimited (hypothetical)
Moderate	20% below 1990 level (hypothetical)
High	50% below 1990 level (hypothetical)

Source : Manne and Richels, 1993

If the damage potential proves low, then carbon emissions would remain unconstrained. With a moderate damage potential, the 2010 target would be 20 percent below 1990 levels, and with a high damage potential, the 2010 target would become a 50 percent reduction (incidentally, this might not be possible to be implemented at that time).

Under a “act-then learn” hedging policy, decisions would be taken at discrete points of time separated by intervals of one decade. It would be assumed that prior to 2020, the energy sector’s supply and demand decisions should be made under uncertainty about reaching a consensus on

carbon limits. From 2020 onward, it would be supposed that decisions would be made after the resolution of uncertainty. Under the "act-then learn" strategy, we would make decisions for 2000 and 2010 without knowing which of the states of the world (low, moderate, and high damage potential) would occur and should select an optimal hedging policy for the emissions levels¹⁶.

A sequential hedging strategy consists of adopting an emissions level that lies between the extreme cases shown by different emissions scenarios, and the size of the hedging strategy will depend on the probabilities assigned to alternative outcomes. To illustrate a case in which the expected value of perfect information (EVPI) would be high, and in which the probability of low damage would be 60 percent and that the probability of a 20 percent reduction 1.5 times that of a 50 percent reduction, then, Manne and Richels (1992) conclude, if controls are required, they are more likely to be moderate than high.

One another example of a sequential decision making is reported by Hammitt *et al.* (1992). According to well publicised works (see also Singer *et al.*, 1991; Manne and Richels, 1991, 1992; IUCC, 1993; Richels, 1994; Peck, 1994), first decisions might be to take those actions where the cost is not high while considering more aggressive-reduction policies (Fig. 2.6-2).

First, energy conservation represents a set of low-cost, quickly implemented policies. To illustrate, if adopted at t_0 , energy intensity falls 30% over 20 years (Hammitt *et al.*, 1992). This corresponds to some minimal agreement made of two complementary actions: conserve energy by discouraging wasteful use globally, and improve efficiency in energy use (Singer *et al.*, 1991).

Second, fuel switching represents a more aggressive-reduction policy. It is a set of high-cost, slowly implemented emission-reduction technologies. They are produced by long-lived capital equipment using either emitting or non-emitting technologies (fossil fuel vs. nuclear, solar, biomass). Both have construction periods of about 10 years, and an operating period of roughly 30 years (Hammitt *et al.*, 1992). The motto is: use non-fossil fuel energy sources wherever this makes economic sense (Singer *et al.*, 1991). "The policy decisions are whether to begin substituting non-emitting or emitting equipment, and if so, the rate at which to substitute, specified as the transition half-life, or the time until half the capital stock then operating is non-emitting" (Hammitt *et al.*, 1992).

¹⁶ The period-to-period allocation of carbon emissions is determined so as to maximise the expected discounted utility of consumption (Global 2100 by Manne and Richels, 1992).

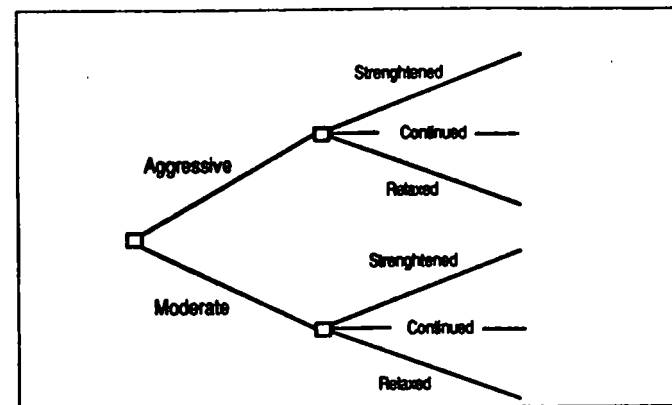


Figure 2.6-2: Decision tree for sequential policy choice.
At the beginning of the first period, (1992) either the moderate reduction or aggressive reduction near-term abatement policy is selected. At the beginning of the second period (2002), uncertainties about climate sensitivity and the damages of climate change are substantially resolved and the chosen policy is amended to limit climate change to the "optimal" level. Hammitt *et al.*, (1992).

Hammitt *et al.* consider two near-term policies, aggressive and moderate reduction (Fig. 2.6-2).

Under the aggressive-reduction policy, conservation and fuel-switching are adopted together starting in 1992.

Under the moderate-reduction policy, only the conservation policy is adopted and implemented in 1992. At the beginning of the second period (2002), uncertainties about climate sensitivity and the damages of climate change are thought to be substantially resolved and the chosen policy is amended to limit climate change to some "optimal" level (though this could appear as an irreversible process).

2.6.1.3 Clearing up the uncertainties? The value of improved information

Under a "learn-then act" sequential decision making, the value of new information depends on changes in the probabilities assigned to the (alternative) scenarios before and after the study. "If the probabilities of (alternative) scenarios remain equal, then the value of the study is zero; if, on the other hand, only one scenario can be selected, a study might be worth as much as 100 billion dollars" (Shlyakhter *et al.*, 1995).¹⁷

¹⁷ Values of situations before and after imperfect or perfect information is received can be computed. When there is risk neutrality, these values also represent expected utility. Suppose that expected results are as follows: (a) without information: +150; (b) imperfect information: +325; (c) perfect information: + 500. This hypothetical example "illustrates a perfectly general result: the value of perfect information (500 - 150) clearly exceeds the value of imperfect information (325 - 150)"; it also indicates that some information—albeit imperfect—is better than no information at all (Eeckhoudt and Gollier, 1995). Hourcade and Chapuis (1994) have shown that, accounting for climate change related surprises under

Under an "act-then learn" sequential decision making, there is an agreement that uncertainty cannot be resolved before a decision is taken. This does not mean that uncertainty is an obstacle for decision making. This means that first, its resolution is at a too high a cost and, second, that maybe it will not facilitate a decision—clearing up the uncertainties could make the greenhouse warming issue more difficult to resolve (Waterstone, 1993). Accordingly, it is for instance assumed that the damage potential will remain unknown until 2010-2020. As a consequence, the appropriate emissions level would be known only well into the second decade of the twenty-first century. The actual level of investment is also influenced by the conflict between the long term nature of the problem (and the time that would be required for resolution of the uncertainties) – and the short term public and private decision makers horizons (sometimes called NIMTOO phenomenon). Today decisions must thus consider the partial disclosing of the uncertainties along with the long-term effects of short term decisions. Sequential decision making can address this point.

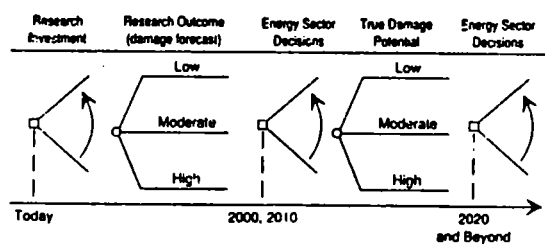


Figure 2.6-3: Decision tree for value of information analysis.
Source: Manne and Richels (1992)

A decision tree reflecting this type of sequential decision making can be adapted from the one in Figure 2.6-1b. Figure 2.6-3 shows this for the energy sector's near-term supply and conservation decisions that must be made with respect to the uncertainty regarding the ultimate damage potential. In this case, the degree of uncertainty is represented by a likelihood table indicating the probability that the damage forecast will be low, moderate, or high—given that the true damage potential is low,

a sequential decision model, a resolution of uncertainty had high value relative to no-regret potentials and technical innovation. Peck and Teisberg (1992) and Manne and Richels (1992) show similar results.

moderate, or high (conditional probabilities; cf. Manne and Richels, 1992).

This representation allows the use of standard probabilistic techniques to incorporate the outcomes of the research program in the decision model (Global 2100, in this case).

Maximum accuracy, or perfect information, would eliminate the need to hedge against surprise. Accuracy of the forecast, however, will not be maximum. We therefore have to accommodate with hedging under imperfect information. In this case, the research outcome will lead to a revision of our beliefs. It will help at modifying near-term decisions.

A sequential decision making strategy made of acting and learning decision making paths would be the best strategy.

2.6.2 Exploring mutual insurance decisions and markets for risk

Insurance is one another way to respond to risks and uncertainty which is worth to explore.¹⁸

Transferring risk from one agent (country) to another or sharing risk collectively does not make the risk disappear though restrictions can be attached to that kind of transfer. Yet, under what conditions, and why will an agent (country) demand insurance to cover possible climate change damages? Can market evaluate the price of climate change risk? How would the allocation of risk be decided?

Exploring insurance decisions means addressing the problem of determining the economic value of things. In particular, it goes much further than simple knowledge of costs and benefits of climate change; that is, risks. Exploring insurance decisions and, consequently, markets for risks is addressing the possibility of determining the final allocation of these risks. Who bears the economic risk of the possibility of climate changes which is one of the large risks of our modern economies?

In particular, do transfers of risk improve welfare in an economy (or is it instead a 'zero sum game')? It appears from the literature that "the transfer of risk is a potential source of large improvements in economic efficiency and social welfare" (Eeckhoudt and Gollier, 1995).

Insurance markets leave uncovered collective or correlated risks such as the risk induced by

¹⁸ The word 'insurance' is sometimes abused in climate debate. For instance, the insurance premium of, e.g., Manne and Richels (1992) is in fact a risk premium in the Arrow-Pratt sense (the Arrow-Pratt insurance premium describes situations where, because of risk aversion, people are willing to pay more than expected yearly damage), and the insurance scheme of AOSIS is in fact a liability scheme (see below). In addition, one can think that there is no analogue between the impact of climate change and the insurance market because climate change is not an isolated event, and that to control portfolios of insurances requires the risks to be fairly well known. Yet, the insurance industry is currently giving up because of increasing losses that are not indispensably linked to climate change-related natural catastrophes such as a new insurance orchestration must anyhow be envisaged. Simple evidence is given here to decision makers (the approach is purely normative due to the absence, to date, of any applied analysis of climate change insurance scheme). Note that the impacts of extreme events on property insurance market and adaptation to climate change by property insurers are the concern of IPCC WGII Chap. B9 on "Financial Services" and consequently are out of the scope of this section.

1 Ignorance of the true frequency distribution of harmful events. According to Chichilnisky and Heal
2 (1993), our ignorance of the frequency of the impacts of climate change constitutes a collective risk.
3 This collective risk can be allocated through markets for securities that pay off contingent on that
4 frequency. For the individual risks that remain, it is more practical to use mutual insurance contracts:
5 this is done by having a different individual insurance contract for each possible frequency of
6 impacts.

7 2.6.2.1 Use of financial markets

8 According to Chichilnisky and Heal (1993) an interesting aspect of financial markets is that they can
9 provide a natural mechanism for reconciling differences in assessments of the likelihood of important
10 climate changes between countries, and for testing the conviction behind publicly-stated positions.
11 International markets for risks of climate change would also provide an objective test of the
12 seriousness with which countries adhere to their publicly-professed positions on the risk of climate
13 change.

14 The Arrow-Chichilnisky-Heal idea is then to settle a framework involving securities whose pay-
15 offs depend on which description of the (collective) risk is correct. "Betting on which of several
16 alternative descriptions of the way the world works is correct, is in effect what one does when
17 choosing one research strategy over another. (...) For example, a market for the securities of high-
18 technology firms pursuing different research strategies towards the same goal is a financial market in
19 which these bets are made" (Chichilnisky, 1994).

20 The trading of climate risk positions from a global ecological-economic viewpoint is amply
21 thinkable. In short, ecological models are energy oriented models whereas economic ones are based
22 on the behaviour of individual agents and groups. Under the case for climate change prospects, the
23 behaviour of the agents contributes to make particular energy profiles to appear and develop, with
24 unknown feedbacks on future economic outcomes (Pillet, 1994).

25 Under this perspective, one better has to place the focus on the various matching and diverging
26 points that dynamically occur; that is, on what will possibly emerge from such interconnections. This
27 amounts to allowing agents to identify the set of possible descriptions of the risks that humanity faces
28 and to bet on which model of the climate change related risk is correct.

29 Ecological systems (assets) cannot easily be allocated on the marketplace. Therefore, instead of

1 either *laissez-faire* or to let suboptimal policies being implemented—which for sure are biased
2 against the ecological-economic long run—, trading climate change risk positions that are contingent
3 on which model of the change is correct would *interlace* systems that basically are highly differenti-
4 ated ones. In addition, countries would have to express their estimates on global climatic risks
5 through a market commitment and therefore will have to express their true views. If a country sells
6 securities that pay off in the event that climate changes are not serious and buys those paying off if
7 they are serious on terms that do not correspond to its true beliefs, it will suffer a financial loss
8 (Chichilnisky, 1994, Pillet, 1994).

9 2.6.2.2 Insurability of risks associated to climate change

10 The insurance issue can also be accorded our attention in contrast with mitigation strategies.

11 Basically, in view of uncertainties about consequences of carbon emissions, the question is: Is it
12 worth taking costly and disruptive measures to reduce levels of emission far enough to stop the build-
13 up of CO₂ (Chichilnisky, 1994)? Next, should you consistently decide to wait until more is known
14 and better estimates of the consequences are available, would it not be cautious to insure against
15 harmful events even if the chance of their occurring is small and not immediate? Is a trading of risk
16 positions between regions of the world conceivable?

17 Climate change associated risks are first difficult to quantify (in a classical statistical sense, the
18 probabilities describing them are unknowable). They are then endogenous (once steps have been
19 taken toward reducing climate associated risks), correlated (which demands complex analysis to
20 assess probabilities), and collective (by which the uncertainty about the relative frequency of harmed
21 agents is meant). In principle, however, once frequencies are at least approximately known, actuarial
22 calculations can be set up, and the problem can be conceived as insurable.

23 For instance, to the extent that carbon emissions lead to uncertainties about climate change and the
24 corresponding damage that such changes cause, it can be said that the uncertainty is induced by the
25 industrial countries (to date), and borne by the world as a whole. The available data also indicates that
26 developing countries are more vulnerable to climate change. Any insurance scheme must take this
27 distribution of causes and risks into account.

28 The floods of 1993 in the US, in Bangladesch, and in Europe (France, Switzerland) have reminded
29 us of the profound vulnerability of human settlement to climate. There is considerable natural varia-

tion in these phenomena, although climate scientists expect that variation induced by human activity will soon come to exceed the natural variation.

Box 2.6-2: Natural events and attached insured losses (after Weilenmann, 1994)

Event	Date	Insured Losses (in billion US\$)
Hurricane Gilbert	September 1988	0.05
Hurricane Hugo	September 1989	5.8
Winter storms Europe	January/February 1990	10.0
Colorado storms	July 1990	1.0
Hurricane Bob	August 1991	0.82
Hurricane Andrew	August 1992	15.5
Hurricane Iniki	September 1992	1.6
East coast storms US	March 1993	1.6
Midwest floods US	Summer 1993	0.765

Correspondingly, one must bear in mind that before 1989, natural disasters caused by storm events with insured losses greater than one billion dollars were unknown (Weilenmann, 1994). For insurers, the most costly storm event to date has been 1992 hurricane "Andrew" with insured losses of US\$15.5 billion (see Box 5.2-II). This kind of losses has become more frequent and a potential rise is predicted on the standpoint of the insurance industry (Weilenmann, 1994). However, the causes for that trend are not clear and are not conclusively linked to current "greenhouse activity". They seem to primarily depend upon the increasing concentration of people and insured economic values in areas of high risk although losses in climate related disasters have been increasing since the 60s at a rate 3 times that in earthquakes (Yokohama document, 1994).

2.6.2.3 A market framework to respond to collective risks

Next, what a society believes it to be worth paying to reduce the risk of climate change depends inter alia on two key characteristics of that society: its *degree of risk aversion* and its *discount rate*.

The degree of risk aversion is a measure of how much an individual or group is willing to pay to avoid a risk.¹⁹ The discount rate is an equivalent measure of the value of the future relative to the present (see Chapter 4).

It consequently turns out that different country's positions with respect to measures to restrict

¹⁹ An indication of the degree of risk aversion can be obtained by the following exercise: offer a person the choice between either \$0 if a tossed coin comes down heads and \$100 if it comes down tails or \$50 with certainty. Most people will choose \$50 with certainty, even though on average they will get the same by choosing to bet on the tossed coin and they stand some chance of doing better (and some chance of doing worse). In fact most people will choose \$45 with certainty to a bet on a tossed coin giving \$0 for heads and \$100 for tails. Suppose that \$45 is the smallest amount for which this is true. Then the difference between \$45, the reward in the risk less situation, and \$50, the average reward in the risky situation, is a measure of the person's risk aversion. The more risk averse you are, the more you will insure (Chichilnisky, 1994).

greenhouse gas emissions depend on their discount rates and degrees of risk aversion (even if there were complete agreement about all of the scientific aspects of the global change problem, there could still be disagreement about policy responses). Differences in policy positions could then be attributed to differences in discount rates and degrees of risk aversion rather than, or in addition to, different interpretations of the current scientific evidence.

Yet, different perceptions of the risk involved do not however preclude efficient solutions. Differences in attitudes toward risk could merely lead to the introduction of new markets in which different risk positions are traded, with efficiency gains. Economics is about differences in preferences leading to trade (Chichilnisky, 1994). Betting on climate states could be envisaged, not only because insurance can be provided within a market framework, but basically because there exists an ecological-economic ground for the use of financial instruments in addressing climate change collective risks induced by uncertainty about the overall/regional distribution of adverse effects (Pillet, 1994).

The institutional structure to be developed would use two types of financial instruments in order to deal with the two above-mentioned aspects of the problem. The aim is to obtain an efficient allocation in the face of those risks. One instrument is a *mutual insurance contract* which is tailored to deal with the risks faced on a regional basis by communities contingent on the distribution of harmful effects world-wide. The other one is related to *Arrow securities* because we need such securities to deal with collective risks induced by strong uncertainty about the overall distribution of adverse effects.

A *mutual insurance contract* is an agreement between parties subject to similar risks that those who are harmed will be compensated by those who are not.²⁰ In the climate change context, one can think of groups of communities subject to the possible impact of that change, with those unharmed compensating the others. To illustrate, the *Alliance Of Small Island States* (AOSIS) has proposed that an "International Insurance Pool" be established to cover climate change impacts. The *Pool* would take the financial burden suffered by affected developing countries and distribute it amongst the industrialised countries. The members of the *Pool* would be divided into two groups. The first group would consist of low-lying coastal countries and small island states that would receive insurance coverage from the fund. The second group would include industrialised countries who would

²⁰ Examples are agricultural co-operatives of the type recorded in Europe at least since the fifteenth century, and the nineteenth century UK workers' associations and friendly societies. These involved agreements between a group of workers that if one were sick and unable to work, he or she would be compensated by the others.

1 contribute funds (after IUCC, 1993).

2 Mutual insurance contracts would mean making transfers, the size of the latter depending on the
3 overall level of prosperity, and the transfer per se being contingent on the overall incidence of
4 negative effects (in the sense of high or low overall incidence of negatives climate change-related
5 events in the population and in ecosystems).

6 The AOSIS proposal calls for *Pool* contributions to be collected in 2004, ten years after the *Climate*
7 *Change Convention* enters into force—provided the rate of global mean sea-level rise has by then
8 reached an agreed figure. This ten-year delay has been thought to give the funding countries sufficient
9 time to make their initial investments. If sea-levels have not risen too much by the time the ten-year
10 period expires, a review of conditions would be undertaken.²¹

11 The *securities* we would need to deal with collective risks induced by uncertainties about the
12 overall distribution of adverse effects would pay out if and only if there were a particular frequency
13 of damage in the world as a whole. This would involve identifying the set of possible descriptions of
14 the risks that humanity as a whole face, which are called here collective risks. Climate-related events
15 such as floods, tropical storms or certain temperature patterns are examples.

16 Introducing, therefore, securities whose payoffs depend on which description of the risk is correct
17 would allow agents to bet on which model of the risk is correct. A similar financial instrument is
18 already in use to hedge against environmental uncertainties and risks: *CAT Futures* (for *Catastrophe*
19 *Futures*). This instrument is a security which pays contingent on the frequency of the occurrence of a
20 major weather risk, such as tornadoes in the East Coast of the US, and floods in the Midwest. *CAT*
21 *Futures* are traded by insurance companies to hedge against their exposure to major climate risks as
22 some sort of reinsurance scheme.

23 Yet, would insurance companies be able to address global climate change risks? Currently not. A
24 new financial structure has to be set up.

25 For the insurance industry, which is used to drive fixed, short-term contracts, climate change intro-
26 duces new circumstances “in ways that mean traditional practice and the old statistical methodologies
27 are no longer adequate”. Climate change implies a certain degree of irreducible unpredictability be-
28 yond the category of risk-like uncertainties For insurance companies, “past experience is no longer a

²¹ Others would say: the island countries would have to contribute some funds to the *Pool*. Note that the AOSIS proposal was presented to the negotiators of the *Climate Convention* but was not included in the final treaty—and that it is closer to a liability scheme than to an insurance contract.

1 safe guide to the far future” (Ayres and Weaver, 1994). The current trend in the insurance industry
2 with respect to weather events is a clear attempt at modifying the underwriting guidelines by setting
3 restrictions on coverage (exclusions), at setting total exposure limits for a specific high risk zone to
4 avoid the cumulation of risks (for instance the Eastern coast of US, Japan, Australia, low lying coastal
5 areas), or at improving overall risk exposure by selective underwriting.²²

6 To conclude, the markets just described can provide a natural mechanism for reconciling differ-
7 ences in assessments of the likelihood of important climate changes between countries, and for testing
8 the conviction behind publicly-stated positions (Chichilnisky, 1994). Accordingly, this could be help-
9 ful in advancing negotiations between industrial countries with different perceptions of the risks, such
10 as the US and the EU (also see Pillet, 1994)²³ as well as in correcting the North-South balance
11 between the causes of climate risks (in the North), and the ecological-economic impacts of the risks
12 (which are believed to be more serious in developing countries).

13 2.6.3 Portfolio Analysis Analogy

14 Numerous policy measures are available to limit the impacts of climate change. Countries will typi-
15 cally implement several of these policy measures since no one measure is clearly superior. Indeed, the
16 decision-maker’s problem is much more complex than the choice of a single action/policy measure to
17 the exclusion of all others. In practice, it is a question of constructing a *portfolio* of actions/policy
18 measures with the goal of best using the opportunities to diversify that are present in the economy.²⁴

19 Although governments will be making climate change decisions for most of the next century, this
20 does not mean that they have unlimited opportunities to adjust the size and mix of their portfolio of
21 climate change policies. The total resources devoted to measures to limit climate change (the size of
22 the portfolio) and the mix of measures implemented (the mix of the portfolio) cannot be changed as
23 often as governments deem appropriate because of lock-in effects as well as other time-, attitude-, and
24 scientific results-related factors. In many cases, instead of making decisions, options will be taken.

²² Swiss Insurance Industry, anonymous executive. Pers. com., 1994.

²³ Suppose for example the US believes it most likely that there will be little climate change, and the European Union believes otherwise. Then through the market for securities whose payoffs depend on which description of climate change is correct, the US will naturally sell insurance to the EU. The US would wish to be a seller of securities which pay if climate change is serious, because of its belief that this event will not occur, and a buyer of securities that pay if it is not, because of its belief that this will be the outcome. The EU would be on the opposite sides of these markets. (Chichilnisky, 1994).

²⁴ This portfolio is not the same as a portfolio of an investor; however, decision makers should envisage the evaluation of the expected return and the risk of that portfolio.

2.6.3.1 Selecting a portfolio

In this respect, the key for selecting an optimal portfolio is to understand how the options interact —e.g., better greenhouse information will influence technology development and emission reduction decisions (Manne and Richels, 1993).

In principle, the policy measures/options available to countries to limit climate change and its impacts include:

- technology research aimed at improving the cost-effectiveness of greenhouse gas mitigation technologies such as energy efficiency and non-fossil energy sources;
- joint implementation, technology transfer and other forms of international co-operation to limit climate change;
- phasing out existing policies, such as subsidies to fossil fuels, that reduce welfare and directly or indirectly increase greenhouse gas emissions;
- measures to reduce emissions, or increase sequestration, of greenhouse gases;
- measures to adapt to the consequences of climate change;
- insurance orchestration to hedge against risks revealed by strong/unexpected uncertainties;
- insurance for additional costs incurred due to adaptation.

The specific policy measures available vary from country to country; research capabilities vary, the inefficient existing policies vary, the costs and availability of measures to reduce greenhouse gas emissions vary, the costs and availability of measures to increase sequestration of greenhouse gases vary, the damages due to climatic change and the measures for adapting to these damages vary.

A portfolio manager attempts to get the best return given a level of risk (as derived from a given level of uncertainty of a given type). The appropriate level of risk can be derived from the investor's assets using assumptions about maximising expected value behaviour. The investor can also impose constraints on the portfolio to reflect his or her preferences. Investing some or all of the funds in "environmentally friendly" assets or prohibiting investments in specified industries, regions, or assets for ethical reasons are examples of such restrictions.

Countries likewise will select a portfolio of climate change policies that reflect, at least implicitly, a variety of objectives and constraints. A country may look for the economically optimal portfolio of climate change policies. However, considerations of the impacts of the policy mix on different socio-economic groups, international equity, and intergenerational equity are likely to come into play. These objectives will have different weights and will vary from country to country. The "right" blend of options will include political costs and institutional capacities and is a decision which each

political system must take for itself (countries do not use information; government departments may use information).

2.6.3.2 No operational model is available

An operational model to analyse the optimal portfolio of climate change policies for a country is not feasible given the state of our knowledge. But even the sparse information on the expected costs and benefits of some amongst the broad policy options can yield some useful insights.

- Peck and Teisberg (1993), and Manne and Richels (1993) have estimated the value of spending on climate research. It is shown that the expected return is several times the current level of climate research spending. The same analysis could be performed for technology research. To better encounter uncertainty, the main idea is to consider spending on climate research and climate-related technology improvements as an risk premium, and not as subsidies to be randomly allocated. Indeed, the key for selecting an optimal portfolio is to understand how the options interact, e.g., better greenhouse information will influence technology development as well as emission reduction decisions.
- Several researchers compare the costs of unilateral action and international co-operation to address climate change. The analyses consistently show large returns to international co-operation. International co-operation should however contain an instrument by which welfare can be redistributed among nations. If it is not the case, as shown by Pillet et al. (1993), small countries with a comparative advantage in the production of clean commodities and a high emissions reduction marginal cost, might have arguments for doing nothing and thus adopting a free-rider behaviour until a complete international climate agreement is concluded.
- An OECD analysis of the effects of phasing out existing inefficient policies suggested that greenhouse gas emissions would be reduced by over 25% with a net economic benefit. In many cases eliminating existing subsidies is politically very difficult, nevertheless a large net benefit is possible from this policy.
- An emissions reduction supply curve or other analysis of the costs and potential emissions reductions that could be achieved through a wide range of specific measures has been conducted for many countries. Virtually every study shows that some emissions reductions are possible at very low, possibly negative, cost. Many of the measures also yield other environmental benefits such as reductions in acid rain, ground-level ozone precursors, and toxic discharges.
- Adaptation measures that reduce some of the damage due to climate change are available in some countries; building dikes to protect low lying coastal areas from sea level rise for example. Such measures can be implemented where they cost less than the damage that would otherwise occur.
- Climate change insurance contracts and transfers, and trading of risk positions between regions and countries can be referred to face unexpected uncertainties and collective risks.

2.6.3.3 *Three main forms of policy options*

It turns out that three main forms of policy options dominate current discussions: continued intensive science research to reduce climate and impact uncertainties, development of new supply and conservation technologies to reduce abatement costs, and immediate emissions reductions in order to slow down climate changes. The issue for the "option-taker" is not one of either-or but one of finding the right blend of options. Policy makers must decide how to divide greenhouse spending among competing needs. What portion goes to resolving climate uncertainties? What portion goes to technology development? And what portion goes to immediate abatement of emissions? (Richels, 1994). Using the portfolio analysis analogy, a country must use the available information to decide upon the size of its investment in climate change limitation and on the allocation of that investment across policy measures.

The size of the investment will reflect the country's objectives and its obligations under international agreements (FCCC, 1992). Assume that the country has ratified an international agreement that specifies national greenhouse gas emissions limits. Then the size of its climate change investment reflects the most cost-effective means of achieving the country's agreed emissions limit plus expenditures on research and adaptation measures. In the absence of an international agreement a country may have little alternative but to implement necessary adaptation measures. Since almost every country accounts for only a small fraction of global greenhouse gas emissions, unilateral actions will have only a negligible effect on the pace and extent of climate change. No country, acting alone will be able to appreciably reduce the damage it suffers due to climate change except by implementing adaptation measures. This suggests that all countries have an economic incentive to reduce emissions of greenhouse gas emissions.

At a global level, benefit-cost analyses can help establish an appropriate level of climate change investment. Climate change policy does not involve a one-time choice—or some go/not go type of decision—between distinct, long-term options (do nothing or implement policy "X" for the next century), the types of decisions to which benefit-cost analysis has historically been applied. Since climate change policy can be modified frequently and incrementally, the "option values" of decisions must also be considered (the option value of deferring action on climate change can be interpreted as an insurance premium to cover the cost of damages that may result).

The level of their investment in climate change policy will be influenced by factors beyond the

strictly economic considerations mentioned above. Expected damage to ecosystems, expected sea level rise, potential socio-economic impacts, international equity concerns, intergenerational equity, and economic development strategies based on development of mitigation and adaptation technologies are examples of other considerations that may influence a country's climate change limitation spending.

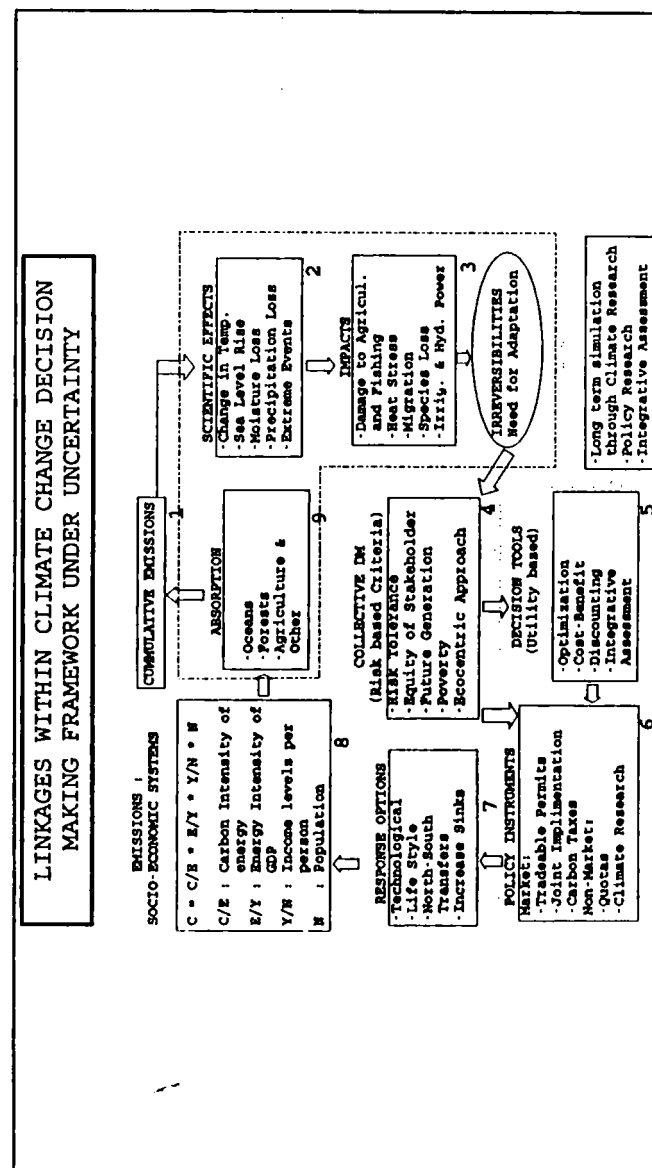
Incorporating option values into the benefit-cost analyses of the policy measures indicates that some action on climate change is economically justified by every country. No country can be confident that it will not incur damage as a result of climate change. Thus, delaying action to limit climate change is an option that has a cost, at least an insurance premium. Every country has available policy measures that have negative or very low costs after accounting for any associated benefits. Thus every country has some climate change mitigation measures that are economically justified.

Normally, the mix of assets in the portfolio is adjusted so that the risk-return ratio is equal at the margin. As discussed above, only sketchy information is available on the expected costs and benefits of the main policy measures. The variability of the costs and benefits for these broad policy options is not known. Governments can make subjective assessments of the variability of costs and benefits of different policy measures. The risks associated with phasing out existing inefficient programs or implementing energy-efficiency measures are lower than those associated with reforestation to sequester carbon or construction of sea walls. The latter offer only climate change benefits while the former also yield other benefits.

2.6 LINKAGES OF CLIMATE SYSTEM WITH DECISION MAKING FRAMEWORK

In this section, we briefly outline the linkages of decision making framework with climate system illustrated in figure 2.8. Each square is fully discussed by various chapters in this report, so we restrain from elaboration. There are two other working groups on scientific and impact assessments, summary of which have to be reflected also in the decision making. Thus, the framework encompasses outcomes of all the chapters in this report and highlights of the other working groups.

The figure shows that the chain of events start from cumulative emissions of greenhouse gases (square 1 in the figure 2.8). These cumulated emissions may trigger off various possible climate related changes such as change in the temperature, sea level rise, moisture loss, precipitation change and extreme events (square 2). These climate changes would in turn have impacts such as damage to agriculture and fishing, migration of population from the coastal areas, species loss, and scarcity of water and so on, which in turn, will constrain irrigation and hydro power generation (square 3). However, the decision making today has to consider climate changes and impacts that may occur 25, 50, 100 years and beyond and respond to it now by formulating, say, 10 or 20 year strategies that have to be periodically revised. Since we do not know what may be in store, we have to rely on climate change research to say how the situation would look at different time periods. Economic costs of adaptation and irreversible damages for these impacts have to be compared with the abatement costs using various decision tools. Thus research results are fed into collective decision making process, which takes into account issues such as inter-regional and intergenerational equity, ecological and poverty considerations apart from the various country specific factors such as risk tolerance and vulnerabilities (square 4). To assess the impacts and to facilitate the decision makers in designing the specific abatement policies, one can use various decision tools such as decision theory, optimization, simulation, forecasting and more importantly integrative assessment models (square 5).



Thus, collective decision making is required to arrive at revised strategies to take into account the new information from climate research, and policy research. This helps to choose the desired concentration levels and emission paths. Allocation of these emission levels among parties requires consideration of current and past emissions, need for development for meeting basic needs and resource endowments and global cost effective criteria. For global cost minimisation, collective decisions are needed to choose among various global policy instruments, such as market based policy instruments, viz., tradeable quotas, carbon taxes, joint implementation, as well as other non-market policies such as setting standards, reduction targets, etc. One can choose a set of instruments or a combination of these instruments to achieve the targets of emission reductions (square 6). This also forms a part of policy research. The choice of a specific policy instrument at national level could be based on a variety of utility based criteria such as cost effectiveness, or cost benefit analysis, which may depend on the discount rate used. The national policy instruments would generate in certain response strategies; these may use utility based criteria (square 7). The response strategies could be chosen from among portfolio of options such as alternative technologies, changes in consumption patterns and life style, increase in the sinks, etc. These response strategies would again have an effect on the socio-economic emissions (square 8). The emissions of GHG would depend on socio-economic factors such as carbon intensity of energy, intensities of the GDP, per capita GDP and population. Land and forest use patterns also matter, but there may be a decreasing trend of the emissions associated with these. Some of these emissions are absorbed by oceans, forests, agriculture and other related activities (square 9). The fraction of the total emissions which could not be absorbed by the sinks accumulate in the environment over a period of time and leads to cumulation (square 1) completing the cycle. Sequential decision making is required periodically to verify strategies.

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Chapter 4

Intertemporal Equity and Discounting

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TABLE OF CONTENTS

SUMMARY	ii
4.1 Introduction	1
4.1.1 Importance of the Discount Rate	1
4.1.2 Toward an Emerging Consensus	2
4.2 Intergenerational Equity	3
4.3 Discounting and the Social Rate of Time Preference	5
4.3.1 Formulation of Prescriptive Approach	6
4.3.2 The Pure Rate of Time Preference Across Generations	7
4.3.3 Discounting Utility for Human Extinction	8
4.3.4 Discounting Utility for Acceptable Optimization Results	9
4.3.5 Discounting Utility for Empathic Distance	10
4.3.6 Discounting for Rising Levels of Consumption and Utility	11
4.3.7 Relationship between the Social Rate of Time Preference and Market Rates of Interest	12
4.3.8 Discount Rate Estimates -- Prescriptive Approach	13
4.4 Formulation of Descriptive Approach	14
4.4.1 Returns to Investment	14
4.5 Discounting for Risk	17
4.6 Producer or Consumer Interest Rates?	17
4.7 Discounting Environmental Impacts	19
4.8 Implications for Sustainable Development	20
Annex 4A	23
Endnotes	27
References	28

SUMMARY

The methodology for comparing effects at different points in time, and especially establishing trade-offs across different generations is a matter of philosophy (and for some, religion and morals) because it involves reaching judgements about what is fair or just. The issue is also a matter of economics, because comparisons across time are appropriately judged in the light of changing standards of living over time as well as opportunities for productive investment.

Intergenerational Equity

Climate policy raises particular questions of equity among generations, because future generations are not able to influence directly the policies being chosen today that will affect their well-being and because it might conceivably not be possible to compensate future generations for reductions in well-being that might be caused by current policies. A proper formal treatment of fairness among generations poses special challenges to economic science.

The report of the Commission on Environment and Development called for "sustainable development," defined as economic activity that "meets the needs of the present without compromising the ability of future generations to meet their own needs." Similarly, Brown-Weiss (1989, 25) has argued from the standpoint of international law that "each generation is entitled to inherit a planet and cultural resource base at least as good as that of previous generations."

Among economists the standard approach has been to summarize views about interpersonal equity in the form of a *social welfare function*. Arguments then turn on the ability to derive a particular social welfare function from sound theoretical principles, and about the resulting reasonableness of its derived implications.

Discount Rate

The discount rate is the analytical tool economists use to compare economic effects that occur at different points in time. Identifying the proper discount rate is probably the single most important analytical step in economic analysis of climate change. It is also the most profound ethical question, since it inherently confronts present pain of abatement cost against damages suffered by future generations if no action is taken.

The literature on the appropriate discount rate for climate change analysis can be divided into two approaches. The **prescriptive** approach asks whether a particular program would make society better off, given a plausible social welfare function. The discounting rules specify how consumption at different dates should be valued to provide the correct answer to that question. The **descriptive** approach focuses on intertemporal efficiency and opportunity costs.

Prescriptive Approach

The prescriptive approach discounts consumption accruing to different generations using the "social rate of time preference" (SRTP):

$$SRTP = \rho + 0g$$

1 where ρ is the rate of "pure" time preference, θ is the absolute value of the elasticity of marginal
2 utility, and g is the growth rate of per capita consumption.

3
4 The first term (ρ), the rate of pure time preference, is the rate at which utility is discounted because
5 it occurs later rather than sooner. The second term (θg) is the rate at which changes in consumption
6 levels are discounted to be translated into the resulting changes in utility or welfare levels. If per
7 capita consumption is growing a rate g , then an extra unit of consumption in the future should be
8 discounted by the term θg to take account of the lower marginal utility of consumption at higher
9 consumption levels. This approach takes into account *opportunity costs in calculating changes in*
10 *consumption*, but in valuing the changes in consumption, uses the SRTP.

11
12 With high rates of productivity increase (and high g), of the order of 1.5%, and high values of the
13 elasticity of marginal utility (θ), the social discount rate is of the order of 3%; with low rates of
14 productivity increase, of the order of .5%, and low values of the elasticity of marginal utility, the
15 social discount rate is of the order of .5%. There is no reason why the discount rate should be
16 constant over time even if ρ and θ are constant, since g need not be constant. Developing countries,
17 with high rates of per capita income growth (5 to 8% per year in some countries), and elasticities of
18 marginal utility of 2, could justify discount rates of the order of 10% to 16%. Countries with per
19 capita incomes close to subsistence levels could have high elasticities of marginal utility (rapid
20 dropoff of marginal utility from initially extremely high levels associated with privation), and so
21 justify high discount rates even if they were experiencing slow growth of per capita income.

22 23 Descriptive Approach

24
25 The descriptive approach to the discount rate looks at returns to investments in the real world, and
26 with this information seeks intertemporal efficiency. It asks: could consumption be increased at one
27 date without decreasing it at any other?

28 Market rates of return usually exceed the SRTP. Conceptually, funds could then be invested in
29 projects that provide a higher return with the proceeds being used to increase future consumption. In
30 the context of climate change, however, society is not likely to be able to set aside investments over
31 the next three centuries and earmark the proceeds the eventual compensation of those adversely
32 affected.

Chapter 4 Intertemporal Equity and Discounting

4.1 Introduction

This chapter concerns the methodology for comparing effects at different points in time, and especially establishing trade-offs across different generations. How we think of these trade-offs involves issues of intertemporal equity. This issue is a matter of philosophy (and for some, religion and morals) because it involves reaching judgements about what is fair or just. The issue is also a matter of economics, because comparisons across time are appropriately judged in the light of changing standards of living over time as well as opportunities for productive investment. To reflect the balance of issues, an alternative chapter title would be **Intertemporal Equity, Discounting, and Economic Efficiency**.

4.1.1 Importance of the Discount Rate

The discount rate is the analytical tool economists use to compare economic effects that occur at different points in time. Identifying the proper discount rate is probably the single most important analytical step in economic analysis of climate change. It is also the most profound ethical question, since it inherently confronts present pain of abatement cost against damages suffered by future generations if no action is taken.

The issue of choosing an appropriate discount rate has been discussed in the context of general cost-benefit analysis (chapter 5) for many years (Dasgupta et al. 1972, Harberger 1976, Little and Mirrlees 1974, Sen 1967, Stiglitz 1982). The long term perspective required for sustainable development suggests that the discount rate might play a critical role in intertemporal decisions concerning the use of environmental resources.

The emission of carbon dioxide causes effects likely to persist on a time scale of centuries. IPCC (1990a) estimates that the first half-life of CO₂ is 50 years and the second half-life another 250 years (with the decline to 1/e taking 120 years). In the absence of policy intervention carbon dioxide concentrations could continue to rise for the next 300 years, given current fossil fuel resources (Sundquist, 1990). Climate change thus poses unusual problems for economic analysis, which more typically considers issues with time scales of only a few decades at most.

The usual formulation for discounting over time involves exponential growth of the discount (or value-shrinkage) factor. Thus, one unit of consumption that arrives t years from today is equivalent to the fraction $1/(1+i)^t$ of one unit of consumption available today, discounting at rate i .

Social scientists have debated the precise rate to use for global climate analysis (Broome, 1992; Cline, 1992; Nordhaus, 1993). There is general agreement that the choice of the

discount rate has extremely powerful effects on the economic evaluation of policy on climate change because of the unusually long time horizons involved (e.g. Schmalensee, 1993). With benefits of greenhouse abatement accruing decades or even centuries into the future, if a high discount rate is used, the benefits get heavily discounted relative to the expenditures incurred today in trying to mitigate climate change.

For example, rates of 8% - 10% per annum are often used in project analysis. Such rates cause the future to vanish rapidly. Thus, discounting at 8%, damage of \$1 billion 50 years from now is valued at only $[\$1 \times 10^9]/(1.08^{50}) = \$21.3$ million; and the same damage 200 years from now, at only \$200. This collapse of future values suggests the need to think especially carefully about proper discounting for climate change analysis.

4.1.2 Toward an Emerging Consensus

The framework of an emerging consensus on discounting for climate change analysis would include the following.

First, although economists have disagreed about (a) whether future generations at levels of welfare or utility equal to those of today should nonetheless be discounted relative to the present, and (b) how precisely to relate changes in the discount factor to changes in income, there is widespread (but not universal) agreement about the following propositions:

(i) Rejection of environmentally specific egalitarianism: future generations can be compensated for some environmental/natural resource effects by offsetting accumulations of capital.

(ii) Acceptance of more generalized (but not, usually, absolute) egalitarianism: differences in the overall standard of living should be reflected in the discount rate. There is, in fact, remarkable consensus in the quantitative magnitudes by which future discounting should be affected by rising per capita income. Given the best available forecasts, expected increases in the standard of living should cause discounting of changes in consumption of future generations on the order of 1/2 to 3 percent annually.

Second, trade-offs of consumption across generations, while affected by observed market (producer) rates of interest, through the effect of market rates on the value of foregone investment alternatives, are not in general equal to these market rates.

Third, trade-offs across generations in environmental goods (or public goods) need not correspond to trade-offs across generations in private consumption goods. The standard economist's procedure for dealing with this problem is to convert other goods into their equivalent in private consumption goods, then apply the discount rate to the equivalents. This procedure incorporates market rates of return, by including as a cost of a project the

foregone benefits of possible investments not undertaken.

Fourth, issues of discounting involve the relative values of goods at different dates, and thus intertemporal pricing. Issues of pricing of risk need to be carefully separated out from those involving intertemporal pricing. The standard procedure for conventional models, involving impacts over a single individual's life, involves converting probabilistic consumption patterns into their certainty equivalents, and then discounting at the social rate of time preference -- not the incorporation of an incremental component into the discount rate itself. This procedure does not, however, deal adequately with uncertainties about future rates of growth of per capita income. Such uncertainties are much greater over centuries-scale horizons.

Fifth, issues of equity can be treated in a way analogous to those of risk, through the use of certainty equivalents (Atkinson 1970, Rothschild and Stiglitz 1974), though the likely effect on the appropriate rate of discount have yet to be thoroughly studied.

4.2 Intergenerational Equity

Climate policy raises particular questions of equity among generations, because future generations are not able to influence directly the policies being chosen today that will affect their well-being (Mishan, 1975; Broome, 1992), and because it might conceivably not be possible to compensate future generations for reductions in well-being that might be caused by current policies.

The concern for fairness to future generations has long undergirded the environmental movement. This concern spans a broad range of political, social, and ethical considerations and viewpoints; a proper formal treatment poses special challenges to economic science. Perhaps best known among recent formulations, the report of the Commission on Environment and Development (United Nations, 1987), led by Norwegian Prime Minister Gro Harlem Brundtland, called for "sustainable development," defined as economic activity that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987; for a discussion of sustainable development, see sections 1.6 above and 3.6 below). Similarly, Brown-Weiss (1989, 25) has argued from the standpoint of international law that "each generation is entitled to inherit a planet and cultural resource base at least as good as that of previous generations."

A consensus exists among economists that this does not imply that future generations should inherit a world with at least as much of every resource; such a view would preclude consuming any exhaustible natural resource. The common interpretation is that if the stock of some natural resource be depleted, it be compensated by an increase in the stock of capital (physical or human). Under most calculations, given the savings rates of all but the lowest-saving countries in the world, most countries now pass this test of sustainability. Discussions of intergenerational equity must thus go beyond a focus on sustainable development.

Economists have long debated the equity of discounting distant future benefits (Ramsey, 1928; Mishan, 1975; Rawls, 1971; Sen, 1982). The standard approach to issues of equity since Bergson (1938) has been to summarize views about interpersonal equity in the form of a *social welfare function*, an algebraic formulation relating welfare to levels of consumption of the society's members at a given point in time and across time. Arguments about the choice among alternative social welfare functions then turn on the ability to derive a particular function from sound theoretical principles (seemingly plausible axioms), and about the resulting reasonableness of its derived implications.

While all social welfare functions have been criticized for assuming interpersonal comparability of utility, there seems to be no way of addressing the ethical issues involved in making decisions affecting different generations without making some assumptions implicitly or explicitly about interpersonal comparability. Two polar views are represented by the utilitarian approach, in which social welfare is the sum of utilities; and the Rawlsian approach, in which social welfare reflects the welfare of the worst-off individuals. While the utilitarian approach can be derived from what many view as a persuasive axiomatic (theoretical) structure (Harsanyi, 1955), the Rawlsian approach is derived from a "max-min" strategy (maximize the minimum outcome for any given party) popular in game theory, but which itself does not rest on widely accepted axiomatic principles.

The Rawlsian max-min principle is the strongest in assuring (the least fortunate groups of) future generations levels of consumption at least as great as that of (the least fortunate groups of) the current generation. It is consistent with the Brown-Weiss (1989) approach noted above. The max-min criterion permits inequality in consumption between individuals (or in this case, between

A Dissenting View on Discounting

One prominent economist, Thomas Schelling, has rejected the approach presented here, arguing that it requires the assumption of utility maximization by a single representative individual who lives forever. Schelling emphasizes that the essence of climate change is that those likely to bear the cost of mitigation—the developed countries—differ from those likely to enjoy the benefits—the currently developing countries. Thus he emphasizes the importance of distributional considerations.

Supporters of the approach set out in this chapter note that the model of one immortal individual is used only for exposition, and that the results derived from the social welfare function approach presented here remain true even with many individuals (or countries) within each generation.

generations) only if it improves the position of the poorest. (For the remainder of this chapter, we shall simplify by ignoring inequality within a generation.) In the absence of technical change this would imply that consumption per head should be the same for all generations. By contrast, the utilitarian criterion allows, in principle, future consumption to fall below current consumption, provided the current generation is made sufficiently better off as a result. Correspondingly, it also allows for decreases in present consumption, provided the future generation is made sufficiently better off as a result.

The Rawls and utilitarian social welfare functions can be viewed as limiting cases of more general social welfare functions embracing social values of equality (Atkinson, 1971; Rothschild, and Stiglitz, 1973). In practice, so long as there is sufficient scope for technological change, optimizing any egalitarian social welfare function over time yields increases in consumption per capita. Moreover, with any of the approaches, earlier generations are entitled to draw down the pool of exhaustible resources so long as they add to the stock of reproducible capital.

The individualistic social welfare function, accepted by most economists as the basis of ethical judgments, accepts individuals' own relative valuations of different goods. It does not place separate valuations on unequal access to particular goods, other than through their effects on the affected individuals. For example, Thurow (date) argued that income distribution is a public good, but that its value could be captured in individuals' valuations. Although this represents the consensus view, some economists have insisted that for particular goods, individuals' valuations need not be the basis of societal valuations. For instance, Tobin (1970), in what he called specific egalitarianism, argued that society might argue for greater equality in distribution of health care than would be reflected in individuals' own evaluations. Most economists, however, reject this view.

Sen (1982) similarly suggests a basis for not discounting when environmental effects are in question. He argues that a fundamental right of the future generation may be violated when the environment is degraded by the present generation, and that the resulting "oppression" of the future generation is inappropriate even if that generation is richer than the present and has a lower marginal utility of consumption. In this framework, intertemporal equity for environmental questions requires "a rejection of 'welfarism,' which judges social states exclusively by their personal welfare characteristics."

4.3 Discounting and the Social Rate of Time Preference

The approach described in this section is sometimes called the **prescriptive** approach. It asks whether a particular program would make society better off, given a plausible social welfare function. The discounting rules specify how consumption at different dates should be valued to provide the correct answer to that question. The alternative view, described in Section 4.4, focuses on intertemporal efficiency and opportunity costs. To distinguish it from the prescriptive approach, it is sometimes referred to as the **descriptive** approach.

The question of the appropriate discount rate involves issues in normative as well as positive economics. How ethically should we value impacts on future generations? And to what extent, for instance, will investments made to reduce greenhouse gas emissions displace investments elsewhere? The debate is often confused both because the ethical and efficiency aspects are intermingled, and because there are, in fact, three separate issues that have to be addressed: How do we discount the welfare or utility of future generations? How do we discount future dollars? And how do we discount future pollution? The following discussion summarizes some of the salient issues in the debate, reaching the

following conclusions:

1. Total impacts on consumption (or welfare) across generations: the social rate of time preference, a reflection of societal views concerning trade-offs of consumption across generations, should be employed.
 2. Direct costs and benefits of a greenhouse mitigation project: Suppose that a mitigation project would displace private investment, and that returns to both projects accrue to the same generations. Then it is appropriate to use the opportunity cost of capital - the private return - in discounting.
- Investments in both physical capital (e.g. machines) and human capital (e.g. education) yield on average a positive real return. That is, money invested today can be transformed into more money later, even after adjusting for inflation. Discounting converts each future dollar amount associated with the project into the equivalent present dollar amount that must be invested today in the general economy in order to yield the same future amount.
- Greenhouse gas emission control may be viewed as an investment: money is spent today on emission controls today so that more money (or other benefits) may be received later in the form of reduced economic costs of climate change. If the real rate of return on investment in emission reduction exceeds the rate on investment in machines and education, then future generations would be better off if less were invested today in machines and education and more in controlling greenhouse gas emissions; the converse also holds.
3. Competing investments: The cost of a greenhouse mitigation project must include the foregone benefits of other competing investments not undertaken. Only then will it be appropriate to use the social rate of time preference.
 4. Evaluating risk: uncertainty about the impacts (changes in consumption) can be incorporated by analyzing their *certainty equivalents* (the certain result that would make an individual indifferent between it and the uncertain outcome), and discounting the certainty equivalents in the manner described above.
 5. Evaluating environmental impacts: environmental impacts can be incorporated in an analogous way--converting them to consumption equivalents, and discounting at the rate described above. Under plausible assumptions, the relative price of environmental goods will increase over time, which would have consequences equivalent to adopting a lower discount rate for such goods at unchanged prices.
- #### 4.3.1 Formulation of Prescriptive Approach
- The first issue in the analysis of the discount rate is the question of how we value consumption accruing to different generations. Within the predominant utilitarian (as opposed to Rawlsian) framework, with standard simplifications¹, the fundamental equation

for the discount rate of consumption, or the "social rate of time preference" (SRTP) is:

$$4.1) \text{ SRTP} = \rho + \theta g$$

where ρ is the rate of "pure" time preference, θ is the absolute value of the elasticity of marginal utility, and g is the growth rate of per capita consumption.

The first term (ρ) is the rate at which utility is discounted because it occurs later rather than sooner. Sometimes this term, the rate of pure time preference, is referred to as discounting for impatience or myopia. The second term (θg) is the rate at which changes in consumption levels are discounted to be translated into the resulting changes in utility or welfare levels. The idea is that if per capita consumption is growing a rate g , then an extra unit of consumption in the future should be discounted by the term θg to take account of the lower marginal utility of consumption at higher consumption levels.

Annex 4A sets out the mathematics of discounting. Along an optimal path, with no distortions, the marginal product of capital (equal to the market rate of interest) and the discount rate on consumption both equal $\rho + \theta g$. It is important to emphasize that in using the SRTP approach, we value the total change in consumption at each date, not just the direct outputs of the project. *If the project displaces private investment* that has a high marginal productivity, then there will be a large loss in output and future consumption resulting from the displacement. The prescriptive view takes into account *opportunity costs in calculating changes in consumption*, but in valuing the changes in consumption, uses the SRTP. In short, all effects are converted to their consumption equivalents (as discussed in section 4.6), then discounted at the SRTP.

4.3.2 The Pure Rate of Time Preference Across Generations

Consider pure time preference first. In a society in which income levels are not expected to rise, impatience may still cause a household (or the present generation) to discount the future (generation), that is, to equate a smaller amount of consumption today with a larger amount in the future. In his classic paper on optimal saving, Ramsey (1928, p. 543) judged that any allowance for pure time preference ($\rho > 0$) "is ethically indefensible and arises merely from the weakness of the imagination." Correspondingly, he argued that future generations should have equal standing with the current generation; there was no moral or ethical basis for weighing the welfare of future generations less than that of the current generation.

For an individual, some non-zero value of pure time preference can make sense, because he or she has a finite life and thus uncertainty about being alive to enjoy future consumption. Nonetheless, for a life span of 70 years, pure time preference at even 1 percent per annum implies that consumption at the end of life is worth only half that at the beginning. Evidence also suggests that individuals' discount rates can change over time, with lower discount rates being used for longer time horizons (Thaler and Lowenstein 1989).

Considerations for society as a whole are different. The approach described earlier asks: if society values different generations in a particular way (the social welfare function), how should changes in consumption in different generations be compared? How society values different generations can be viewed then from two different perspectives: 1) How should society value different generations (an ethical approach); or 2) How does the current generation value the consumption of future generations. Ramsey's analysis focused on the ethical presumption that consumption by all generations should have equal value. But this does not exclude the possibility that as a matter of description the current generation gives less value to consumption of future generations.

4.3.3 Discounting Utility for Human Extinction

One argument focuses on the fact that there is no absolute certainty that future generations will exist since any number of catastrophic events could occur. This argument, which might be called the "asteroid effect," might argue that it would make no sense to give up consumption today for the generation 200 years from now because it may not come into existence. Some economists believe it is appropriate for this reason to discount future consumption to reflect the inherent uncertainty in future conditions. However, the probability of human extinction would seem sufficiently small (especially within a time frame of two to three centuries) that the quantitative magnitude of discounting for this purpose is likely to be extremely small.

Thus, according to some estimates the probability that an individual will die because an asteroid hits the earth during his or her lifespan is of the same order of magnitude as the probability that he or she will die in an airplane crash (about one in ten thousand). The chances of earth's collision with an asteroid large enough to cause species extinction (such as the 10-km-diameter object believed by some to have caused the Cretaceous/Tertiary dinosaur extinction) is far smaller (Wetherill and Shoemaker, 1982). However, to be generous to the extinction argument and for purposes of illustration, consider the individual risk at one in 10,000. The three-century horizon appropriate for climate change analysis is about four life spans, so set the probability of asteroid impact over this period at 1/2,500, for purposes of illustration. Then at the end of this period, a given economic effect should be discounted enough to shrink its value by one-2,500th. The discount rate required for this shrinkage is vanishingly small ($= 0.133 \times 10^{-4}$ percent per annum).

Perhaps one reason the optimal growth literature includes discounting for extinction is that most of the literature emerged during the cold war, when nuclear annihilation was more plausible than today. For public policy purposes, even under those conditions it is arguably inappropriate to incorporate analytical assumptions that take as a premise the failure of policy (breakdown into nuclear war). In any event this motive for extinction-based discounting would seem even less appropriate for the future.

4.3.4 Discounting Utility for Acceptable Optimization Results

Another argument for non-zero pure time preference is that setting the rate at zero could imply that the present generation should accept near-starvation consumption levels, and correspondingly low utility, because with even very small returns on investment, an endless stream of future generations could enjoy increased consumption and (to a lesser degree) utility as a result.

To some extent, however, this concern is already addressed in the overall discount rate equation (4.1). As noted, the first term in that equation discounts utility (pure time preference), but the second term additionally discounts consumption to take account of falling marginal utility. The present generation is protected against an optimizing program setting its consumption near zero if the term for elasticity of marginal utility (0) is large enough and marginal utility drops off fast enough to rule out impoverishment of the present generation for gains to future generations.

More fundamentally, a basic concern about zero pure time preference has to do with the mathematics of maximization over an infinite time horizon. If the utility function has no upper limit, any savings-investment optimization problem is not well defined, because the sum of utilities over time is infinite. There is some literature (Weizsacker 1965) proposing criteria (the "overtaking criterion") to address this problem, but the implications of these criteria for climate policy have not been examined.

Even when the optimization problem is made well-defined, for the purposes here, e.g., if there is an upper bound to utility (as in the function in annex equation 4A.3), there is a tendency toward knife-edge results, with one extreme outcome for zero pure time preference and the opposite extreme for non-zero rates. Thus, whereas the concern of Koopmans (1965), Mirlees (1974), and Chakravarty (1969) is that zero pure time preference can suppress current consumption to unacceptably low levels, just the opposite result can be reached in optimization models that take exhaustible resources into account. In some specifications of such models (Dasgupta and Heal, 1974; Solow, 1974a), any pure time preference rate in excess of zero generates the unacceptable result that optimal consumption falls to zero over the very-long term (although Stiglitz, 1974, shows that this awkward conclusion is not robust with respect to alternative assumptions about technological change, production functions, and utility functions).

Knife-edge results can of course result from other properties of utility maximization models as well (depending, for example, on whether the production function has non-unitary elasticity of substitution between factors, or whether capital-augmenting technical change is zero or positive). Focusing on the mathematical and knife-edge complications of optimization approaches, they do not go far toward specifying the proper magnitude for the rate of pure time preference, even though they might be seen as providing a set of arguments that the rate is greater than zero. Thus, considering the infinite horizon in such models, an infinitesimally small but non-zero rate of pure time preference could suffice to

avoid prejudicing the optimal consumption path against the present generation, depending on other assumptions of the model.

A stronger attack on very low discount rates is provided by those models concluding that low discount rates imply unreasonably high savings rates, particularly in poor economies. Only by raising the discount rate to higher, "more reasonable" numbers can savings rates of the kind actually observed be obtained (e.g. Mirlees, 1967; Chakravarty, 1969). This illustrates a general problem with models founded on utilitarianism: they may imply very large sacrifices from one generation or other group. This argument also assumes that the model captures accurately the structure of the economy; typically, however, these models imply much higher rates of return on capital than are in fact observed in LDCs. For example, Chakravarty (1969) assumes constant return on capital at 33 percent. Instead, the small differences between advanced and developing countries in observed rates of return in spite of large differences in capital-labor ratios suggests either that the economies are not on the same production function, or that the constant returns to scale production function models employed are inappropriate. (See Stiglitz, 1988, Lucas, 1988). Manne (1994) uses a standard growth model to examine the relation between discount rates and savings rates in the context of developed economies. He finds that discount rates of one or two percent imply an unrealistically rapid near-term increase in the rate of investment. Manne thus concludes that a rate this low is grossly inconsistent with observed or plausibly anticipated behavior.

Manne's analysis can, alternatively, be interpreted as showing that the intertemporal equilibrium established by market economies differs markedly from that corresponding to the solution of an intertemporal maximization problem based on a reasonable social welfare function. Such results are consistent with standard life cycle models, without government intervention. On the other hand, they are not consistent with dynastic models, in which each generation incorporates into its own utility function the utility of future generations in a manner exactly analogous to the way future generations are incorporated into the social welfare function (Barro date). However, considerable evidence weighs against Barro's hypothesis.

4.3.5 Discounting Utility for Empathic Distance

Rothenberg (1993) and Schelling (1993) have suggested that although non-zero pure time preference might make sense for an initial two or three decades, beyond a certain future point it makes no sense to apply further discounting of consumption for pure time preference. Thus: "as the future recedes... single generations come to be perceived more and more as homogeneous entities (Rothenberg). Similarly: "time may serve as a kind of measure of distance....Beyond certain distances there may be no further depreciation for time, culture, geography, race, or kinship" (Schelling). A graph of the fraction of face value accorded to each successive generation (for constant real consumption) would thus be a series of declining, successively shallower steps that eventually reach a horizontal plateau. A deep plateau signifies major discounting for empathic distance; a horizontal line

beginning and remaining at unity is the zero pure time preference rate across generations recommended by Ramsey. Policy based on empathetic distance (a shelf lower than unity) may be more defensible in a normative sense when the action is refraining from conferring a windfall gain (as in penurious aid budgets) than when it involves the imposition of windfall damage (as in climate change's effects on future generations).

4.3.6 Discounting for Rising Levels of Consumption and Utility

Even if future generations are given weight equal to that for current generations, so that pure time preference (ρ) is zero, there could still be an important basis for discounting future consumption: people are expected to be better off, so that an extra unit of consumption would not be worth as much in the future as today. Thus, if technological change continues to proceed at the rate at which it has over the last century, with productivity and living standards doubling every thirty years or so, then marginal changes in consumption of those future generations should be weighed much less. This consideration is captured by the second right-hand term in equation 4.1.

There are two questions, corresponding to the two elements in the final term of the equation. First, what are reasonable expectations concerning increases in per capita income (growth rate g in the equation)? Second, how should intertemporal differences in expected consumption per capita be translated into social weights, that is, marginal valuations of dollars of future income. This second question refers to the parameter θ , the elasticity of marginal utility. This parameter essentially tells how rapidly the additional utility from an extra unit of consumption drops off as consumption rises.

No consensus on the first question has emerged. The low levels of productivity increase over the past two decades have raised the question: were the high rates of technological change experienced in the decades following World War II an aberration? Or are the low rates experienced from 1973 until 1993 an aberration?

While it is also the case that no consensus has emerged on the answer to the second question, there is a generally accepted methodology for approaching the issue. The evaluation of any individual's consumption can be summarized by a utility function of the form $U = U(c)$ where the parentheses indicate that U , utility, is a function of c , per capita consumption. Marginal utility is positive ($U'(c) > 0$), but it declines as consumption rises ($U''(c) < 0$). That is why if consumption of some future generation is higher, the marginal valuation of its consumption will be lower. The question is, how much lower? Formally, the answer is given by the elasticity of marginal utility (θ) or: $[dU'/U']/[dc/c]$.

Individuals in their day-to-day decision making reveal information about their perceptions concerning their own utility functions, in at least two different contexts: behavior towards risk and intertemporal allocation of consumption. In both contexts, there seems to be a consensus on elasticities of marginal utilities in the range of 1 to 2, even though the empirical studies require strong assumptions about the specific form of the utility function

(symmetric and time-separable).

Thus, one of the most commonly used utility functions, logarithmic utility, implies $\theta = 1$, meaning that if income rises by 1% the marginal utility of consumption falls by 1%. Attempts to estimate this elasticity by Fellner (1967) and Scott (1989) both place it somewhat higher, at 1.5; whereas recent estimates reviewed by Pearce and Ulph (1994) place it in the vicinity of 0.8.

Just as the choice of the rate of pure time preference (ρ) has important implications for intergenerational equity, as discussed above, so does the choice of the elasticity of marginal utility. The more weight the society gives to intergenerational equity, the higher the value of θ . Thus, a value of, say, 3, would mean that it would require a 30 percent rise in the next generation's per capita consumption to warrant a 10 percent reduction in that of the present generation; or, under a bleaker outlook, that if the future generation is expected to be poorer than the present, the present would be prepared to accept a 30 percent reduction in consumption to secure a 10 percent increase in that of the future generation (so long as the two relative consumption levels did not reverse). Even a unitary value is equity oriented, however. When $\theta = 1$, a 10 percent reduction in the richer generation's income will be an acceptable trade-off for a 10 percent increase in that of the poorer generation, even though the absolute reduction of the one exceeds the absolute increase of the other (because the absolute consumption base of the one is larger than that of the other)².

4.3.7 Relationship between the Social Rate of Time Preference and Market Rates of Interest

Economists have long recognized that a competitive market equilibrium yields a (Pareto) efficient outcome, under appropriate conditions (perfect competition, no externalities, etc.). The distribution of income that it yields, however, has no special merit; that is, it does not, in general, maximize any particular social welfare function. It is a well recognized function of government to intervene in the distribution of income, e.g. by establishing programs for the very poor. By the same token, the intertemporal distribution of welfare that emerges from the market will not, in general, maximize any particular social welfare function discussed in the preceding section. While it is a legitimate function of government to intervene to change the intergenerational distribution of welfare, there is no presumption that the government has in fact intervened so that the observed resource allocations are those that maximize intertemporal social welfare. Moreover, in the case of climate change, no one government exists to make these decisions.

In general, the market rate of interest--the relative price of consumption of one generation in one year of its life to consumption in another year--will not equal the SRTP. In standard life cycle models, even with no technological progress and an economy in steady state, there would be no discounting for society's purposes -- each generation is identical, so the marginal utility of consumption of each is the same. Nonetheless, the market rate of interest will be positive in any efficient equilibrium under certain reasonable assumptions about utility functions (such as individual impatience and zero bequest motive; Diamond,

1 1965). In such models the market rate of interest would thus always overestimate the SRTP.
2 Under some special conditions, with governments intervening with non-distortionary
3 taxation to optimally redistribute income across generations, then observed market rates of
4 interest will accord with the SRTP. But these are highly specialized conditions. (See
5 Stiglitz, 1985, Pestieau, 1972). The market rate of interest, of course, remains relevant,
6 because it reflects the opportunity cost of capital; the changes in consumption generated by
7 any change in policy will be strongly affected by the opportunity cost of capital, as the
8 discussion below will illustrate.

10 4.3.8 Discount Rate Estimates -- Prescriptive Approach

12 The approach described in the previous sections, under plausible assumptions, leads to low
13 discount rates for changes in consumption of future generations. With high rates of
14 productivity increase (and high g), of the order of 1.5%, and high values of the elasticity of
15 marginal utility (θ), the social discount rate is of the order of 3%; with low rates of
16 productivity increase, of the order of .5%, and low values of the elasticity of marginal
17 utility, the social discount rate is of the order of .5%.

19 It must be emphasized that these **discount rates apply to consumption only**, and that they
20 can be applied only after the foregone benefits of other investments have been included in
21 the costs of the program.

23 In general, there is no reason why the discount rate should be constant over time even if ρ
24 and θ are constant, since g need not be constant. In fact, if we assume a gloomy scenario
25 where future output and consumption decline, then g and thus the SRTP may be negative
26 (Munasinghe, 1993).

28 Developing countries, with higher rates of productivity increase, can justify higher rates of
29 discount, at least until the gap between their standards of living and those of the more
30 developed countries have been closed. With labor productivity increases and per capita
31 income growth of the order experienced by the Asian miracle countries of 5 to 8% per year,
32 and elasticities of marginal utility of 2, discount rates of the order of 10% to 16% could be
33 justified. Similarly, low-income countries close to subsistence levels could have high
34 elasticities of marginal utility (rapid dropoff of marginal utility from initially extremely high
35 levels associated with privation), so that their SRTPs could be high even if they were
36 experiencing slow growth over long periods. These distinctions have important
37 implications for climate change policy, because they would tend to mean that the calculus
38 of trading off present abatement costs against future benefits from avoidance of climate
39 change damage could be less attractive for developing countries than for industrial
40 countries. However, there are other elements in the calculus that could go the other way,
41 such as the likelihood of higher relative future damage from climate change for the
42 developing countries (see chapter 6).

44 Specific applications in the still new economic literature on climate change have adopted

1 important differences in estimation of the discount rate. To follow the approach suggested
2 by Cline (1992), with a .zero rate of pure time preference (ρ), and using the consumption
3 growth rate of 1.6% per capita from the IPCC scenarios (IPCC 1992) multiplied by an
4 elasticity of marginal utility (θ) of 1.5, gives an SRTP of 2.4%. If instead it is assumed that
5 per capita growth is only 1% (perhaps because of slower growth after 100 years), or if $\theta =$
6 1, then the SRTP becomes 1.5%. After taking account of the share of resources coming out
7 of capital (20% economy-wide, versus 80% out of consumption) and taking into account
8 the opportunity cost of displaced capital and depreciation, the effective discount rate
9 becomes 2% to 3%.

11 4.4 Formulation of Descriptive Approach

13 As noted above, on ethical grounds, it is difficult to support a rate of pure time preference
14 much above zero. On the same ethical grounds, however, it is equally difficult to support
15 development assistance budgets for the OECD countries that average as low as one quarter
16 of one percent of GDP, to cite one example. Yet this is what occurs in the real world. The
17 descriptive approach to the discount rate looks at returns to investments in the real world,
18 and with this information seeks intertemporal efficiency. It asks: could consumption be
19 increased at one date without decreasing it at any other? The descriptive approach says
20 that if a policy is not intertemporally efficient, it should not be adopted.

22 An important difference between the two approaches is that the descriptive approach
23 includes the opportunity cost of capital directly, while the prescriptive approach includes it
24 indirectly, as the box illustrates (and as discussed below with respect to shadow pricing
25 capital). Most climate change optimization models (e.g. Nordhaus, 1993a, b; Peck and
26 Teisberg, 1992; Manne et al., 1993) rely on the descriptive approach. In practice, both
27 approaches may lead to similar results, and similar policy recommendations.

29 4.4.1 Returns to Investment

31 Nordhaus (1994), Lind (1994), Birdsall and Steer (1993), and Manne (1994), among others,
32 have all stressed the importance of the opportunity cost of capital. Most investments return
33 far more than the 1% to 2% suggested above as the appropriate long-term discount rate for
34 consumption. A review of World Bank projects estimated a real rate of return of 16 percent
35 at project completion; one study found returns of 26% for primary education in developing
36 countries. Even in the OECD countries, equities have yielded over 5% for many decades,
37 after corporate and other taxes, comparable to a pretax rate of at least 7%. An investment
38 at even 5% returns 18 times more than one at 2% over 100 years. Thus, society would be
39 foolish to forgo a 5% investment for a 2% investment.

41 Further, selecting a discount rate of 2% implies far more investment than actually occurs in
42 any country now, and thus would require a big jump in savings rates to finance the
43 increased investment. But even if savings could be increased enough to drive the discount
44 rate to one or two percent, climate change investments would still have to compete with

Example: Project Evaluation using prescriptive and descriptive approaches

Suppose a greenhouse mitigation project is under consideration. If undertaken now, it will cost \$1 million. If not undertaken, a new sea wall might be required in year 50, costing \$10 million. If it is necessary, building a sea wall would avoid damages of \$1 million per year.

capital cost: \$1 million
time until damages begin 50 years
cost of sea wall, year 50 \$10 m
avoided damages, years 50,51,52,53,... 1 m/yr
opportunity cost of capital: 5 %

The decision maker has 4 options:

- a. Do nothing (year 0), do nothing (year 50)
- b. Do nothing (0), build sea wall if necessary (50) --
- c. Mitigation project (0), do nothing (50)
- d. Other investment (0), build sea wall if necessary (50)

The stream of benefits is as follows:

Option (year)	0	...	50	51	52	...
a.	0	...	0	0	0	
b.	0		-10	1.0	1.0	...
c.	-1		1.0	1.0	1.0	...
d.	-1		11.5	1.0	1.0	...
			-10			
			=1.5			

At most plausible discount rates, option b dominates option a -- i.e. if the sea level rises, it is better to build the sea wall than do nothing. Option d dominates option c, as investing the \$1 million in year 0 at 5% yields \$11.5 million in year 50, enough to build the sea wall with \$1.5 million left over. But option d may be institutionally infeasible, as there may be no way to put aside \$1 million today and leave it untouched for 50 years in a sort of Fund for Future Greenhouse Victims. If d is infeasible, then the choice between b and c will depend on the value attached to the extra consumption along path b in years 0 to 49; this will depend on the consumption rate of discount.

many other public and private investments offering higher returns. Birdsall and Steer of the World Bank (1993) explain the problem:

... we feel that meeting the needs of future generations will only be possible if investable resources are channeled to projects and programs with the highest environmental, social, and economic rates of return. This is much less likely to happen if the discount rate is set significantly lower than the cost of capital.

That opportunity costs (market rates of return) usually exceed the SRTF suggests the existence of better alternatives than those barely satisfying, say, a two percent rate of return criterion. At this

point the question becomes: why has the SRTF not been brought into accord with observed market rates of return? In the context of climate change, the central argument of the prescriptionists is that other alternatives are not feasible. As suggested earlier, society is not likely to be able to set aside investments over the next three centuries and earmark the proceeds the eventual compensation of those adversely affected by climate change. Even if such a commitment could somehow be made, there would be no guarantee that the rate of return on capital would remain where it is today over this period.

Accordingly, if the long-term consumption rate of discount is 1% to 2%, say the prescriptionists, then a climate change investment returning 2% is better than no investment at all. To the argument that a discount rate of 2% is glaringly inconsistent with observed behavior (e.g., government spending on education or research, development assistance by donor countries), prescriptionists reply that just because the government fails to allocate resources properly in one area is no reason to insist that decisions in other areas be

Estimated returns on financial assets and direct investment

Asset	Period	Real return (%)
High-income industrial countries:		
equities	1960-84	5.4
bonds	1960-84	1.6
nonresidential capital	1975-90	15.1
govt. short-term bonds	1960-90	0.3
U.S.:		
equities	1925-92	6.5
all private capital, pretax	1963-85	5.7
corporate capital, posttax	1963-85	5.7
real estate	1960-84	5.5
farmland	1947-84	5.5
Treasury bills	1926-86	0.3
Developing countries:		
primary education	various	26
higher education	various	13

Sources: Ibbotson and Brinson 1987; Stockfish 1982, 1989; Brainard, Shapiro, and Shoven 1991; Psacharopoulos 1985; Nordhaus 1994, Cline 1992.

consistent with that initial decision.

4.5 Discounting for Risk

The standard treatment of risk in models involving impacts over a single individual's life is not to raise the discount rate for riskier projects, but instead to convert probabilistic consumption patterns into their certainty equivalents and then discount the results at the standard rate. The same should be true for the pure time preference component of the SRTP when discounting across generations. This component should remain unchanged with respect to risk, and the influence of risk should be incorporated in the stream of expected consumption effects instead.

There would seem to be an argument for varying the growth-based component of the SRTP with respect to risk, however. If there is uncertainty about the rate of per capita income growth, g , then consider the effect on the component θg in the SRTP. Suppose there are two scenarios each with 50 percent probability: per capita income growth of 1 percent and per capita growth of 2 percent. There will be two resulting possible streams of marginal utility over time. The stream of expected value of marginal utility will be the average of these two streams. But if marginal utility is a convex function of consumption³, this average will be greater than the stream of marginal utility generated by considering the simple average growth rate over time, 1.5 percent. That is, with diminishing marginal utility, at any point in time marginal utility along the path for 1.5 percent growth will be closer to that of the 2 percent growth path than to that of the 1 percent growth path. Correspondingly, the expected marginal utility path lying halfway between the two scenarios will coincide with the marginal utility stream for a growth rate closer to 1 percent than to 2 percent. Essentially, the expected value of marginal utility is greater than the marginal utility of expected income. On this basis, there would be grounds for reducing the growth-based component of the SRTP under circumstances of risk.

Because the risk in predicting per capita growth on centuries-scale horizons is high, this consideration is particularly relevant for the problem of climate change.

4.6 Producer or Consumer Interest Rates?

A large literature has debated whether, for small changes in consumption levels, observed rates of interest provide the appropriate basis of trading off government expenditures and changes in consumption of individuals of different generations at different dates. In a world in which there was no taxation, no market distortions, and a single individual living forever (or else "dynastic" utility functions in which individuals take full account of their descendants' welfare), society's intertemporal discount rate should presumably correspond to that of the representative individual, and his trade-offs across time would be given by the market rate of interest.

But these assumptions are not generally satisfied, as evidenced by the marked discrepancy

between the lower interest rates on savings typically facing consumers and the higher rates earned on investments by producers.

Part of the source of the frequent confusion about appropriate discount rates is a confusion about what is being discounted. In the social discount rate approach, what is being discounted is changes in consumption at different dates. Typically, in the producer interest rate approach, what is being discounted are the direct cash flows from the project. The two need not be inconsistent; under certain conditions, using producer interest rates in evaluating direct cash flows and using the social discount rate in evaluating changes in consumption will give the same results -- but only under the specialized conditions specified earlier.

Four schools of thought have emerged on the proper discount rate for public policy. One suggests that it should be the producer interest rate, representing the private rate of transformation between investment today and output in the future; one, the consumer interest rate; one, that it should be some combination of the two; and one, that it should have nothing to do with either. In the absence of any non-distortionary intertemporal social welfare maximization by the government, we have already noted the general result that the rate of discount should be neither.

In special cases, however, one of the other three schools of thought may be correct. For instance, if the government were comparing two projects, both of which cost the same, and both of which yielded their output in the same year, then a comparison of the rates of return would provide an appropriate basis of choosing among projects. Cline (1992) proposes a shadow price of capital set equal to the present discounted value of an annuity paying equal annual installments over a lifetime of N years (set at 15 years for the lifetime of typical capital equipment), with a return of r equal to the rate of return on capital, and discounted at the social rate of time preference (SRTP). With plausible ranges for N , r , and $SRTP$, the shadow price of capital tends to be in the range of 1-1/2 to 2 units of consumption equivalent per unit of capital.

If a public project displaced a private project of equal cost, the same reasoning would imply that the government should only undertake the public project if the rate of return exceeded the rate of return in the private sector (Stiglitz, 1982). More generally, when the government undertakes a project, complex general equilibrium effects can be expected. The full consumption effects of these changes (or their consumption equivalents) need to be calculated, and then discounted using the SRTP (Arrow and Kurz, 1970; Feldstein, 1970; Bradford, 1975; Stiglitz, 1982). Implementation of this approach can apply a shadow price of capital to convert all investment effects into their (magnified) consumption equivalents, and then apply the social rate of time preference for consumption to discount the resulting stream of consumption equivalents (Lind, 1982; Gramlich, 1990). A shadow price of capital greater than unity reflects the fact that the rate of return on capital exceeds the SRTP; care must be exercised in evaluating the shadow price and its path over time (Cline, 1992).

Sometimes, as just discussed, one can look at the direct expenditures and apply an adjusted discount factor, the public sector discount rate. There is a large literature emphasizing different aspects of the adjustment methodology. One body of literature emphasizes the effects on consumption versus investment, deriving a weighted average of the consumption and investment rates of return, with weights depending on the respective importance of the sources of finance (Sandmo and Dreze, 1971). Within the literature on optimal taxation and production (where the discrepancy between producer and consumer rates of interest arises from optimally determined tax rates), if the government is relatively unrestricted in the set of commodity taxes that it can impose, the producer rate of interest should be used to discount (Diamond and Mirrlees, 1971; Pestieau, 1974). However, in the more relevant regime in which government faces constraints on the sets of taxes that are imposed, there is no simple relationship between the appropriate public sector discount rate and the producer interest rate (Stiglitz and Dasgupta, 1971, Stiglitz, 1985, 1988).

4.7 Discounting Environmental Impacts

The essence of social discounting is to convert all effects into their consumption equivalents at the proper relative prices, and then to discount the resulting stream of consumption equivalents at the social rate of time preference. Incorporating environmental effects thus does not change the SRTP itself, but requires special attention to the proper relative pricing of environmental goods over time. While there is a generally accepted approach to valuing goods, there is less consensus concerning valuation of environmental impacts, other than those valued solely for their impacts on the production of goods. The question is addressed within the public finance literature in terms of the valuation of public goods. Assume consumers have utility functions of the form $U = U(c, G)$ where G is some public good (e.g., quality of the environment). Then marginal rates of substitution between c at different dates may bear no correspondence to marginal rates of substitution between G at different dates. This implies that there is no justification for discounting environmental degradation at market rates of interest. The appropriate procedure entails converting the environmental change into contemporaneous consumption benefits, and discounting those.

Technical progress and structural change over the past several decades have resulted in improvements in several measures of environmental quality in the developed countries (World Bank 1992). Moreover, recorded reserves of many "exhaustible resources" have actually increased over the last century, accompanied by a fall in their real prices. This provides evidence that continued growth in per capita incomes will result in improved environmental quality in at least some dimensions. Some have supposed, however, that environmental degradation will occur as society grows (Weitzman 1993). If this occurs or, more likely, if the environment is an income elastic good on which people are willing to spend relatively more as their income rises, then the marginal rate of substitution between environmental quality and private goods will systematically change over time, toward a higher relative marginal value of the environment. The result equivalent to using a low (or even negative) discount rate for environmental amenities (see annex 4A), with prices unchanged. However, it is important to reiterate that this process involves properly valuing

future environmental benefits in arriving at the future flow of consumption, and does not change the appropriate discount rate itself at which the consumption stream should be discounted.

Much of the environmental literature critical of cost-benefit analysis, in contrast, argues for a zero discount rate without seeming to recognize the distinction between a zero rate of pure time preference (ρ) and a zero social rate of time preference (SRTP; see, e.g., Daly and Cobb, 1991; Norgaard and Howarth, 1991). But from equation 4.1, so long as consumption growth is positive there will be a nonzero SRTP. Similarly, some modern philosophers make the same mistake (e. g. Parfit, 1984; Cowen and Parfit, 1992).

Finally, there has been considerable discussion about the proper discounting method for environmental projects of institutions such as the Global Environmental Facility of the World Bank (see e.g. Munasinghe, 1993). The method that follows from the social cost-benefit approach is to obtain consumption equivalents of the environmental effects over time and then discount at the SRTP. The consumption equivalents of carbon emissions, for example, can be evaluated by applying the carbon shadow price from models of climate change damage and optimal abatement, so long as those models themselves are implemented with discounting based on appropriate values for the rate of pure time preference and the elasticity of marginal utility (Cline, 1993). Within a fixed institutional investment budget, it may be that the collection of potential projects that successfully passes a cost-benefit test on this basis more than exhausts available funds. If so, efficient trade-offs within the menu of projects will appropriately involve cutoffs at a higher shadow price in funds drawn from the institutional budget -- but always with benefits evaluation based on the consumption equivalence principle just outlined.

4.8 Implications for Sustainable Development

Economics has long recognized the concept of sustainability. Hicks (1938) used the idea in defining net national income. Neoclassical growth theory (Phelps *date*, Meade *date*, Robinson *date*) advanced the idea of sustainability in its formulation of the "Golden Rule": that configuration of the economy giving the highest level of consumption per head that can be maintained indefinitely. A recent extension has proposed the "Green golden rule" (Beltratti, Chichilnitsky, and Heal *date*). The recent economic debate on sustainable development has focused on two issues: 1) intertemporal equity and 2) capital accumulation and substitutability.

Intertemporal equity. Robert Solow's definition (Solow, 1992) focuses on intertemporal equity: sustainable development requires that future generations be able to be at least as well off as current generations. Sustainable development does not preclude the use of exhaustible natural resources, but requires that any use be appropriately offset. Likewise, any environmental degradation must be offset by an increase in productive capital sufficient to enable future generations to obtain at least the same standard of living as those

alive today.

Capital accumulation and substitutability. Solow's definition, and much of economic theory to date, implicitly assumes that substitutes exist or could be found for all resources. If substitution possibilities are high, as most evidence from economic history indicates, then no single resource is indispensable, and intertemporal equity stands as the only crucial issue (Pearce 1988). If on the other hand, human and natural capital are complements or only partial substitutes then different classes of assets must be treated differently, and some assets are to be preserved at all costs.

Some have argued that the future damages from climate change are on the order of 1 to 2 percent of GDP or less, whereas aggressive abatement costs are larger (Nordhaus, 1993). If this is the case, then taking costly actions now to mitigate global climate change later must rest on one of two arguments: First, that prudence calls for avoiding a large-scale experiment with the planet, and avoiding climate change lies beyond normal economic calculus; or second, that the potential exists for large, sudden, irreversible non-linearities with major effects on the economy, particularly the economy of certain countries or regions.

Others have argued that if a longer time horizon is considered than that of the conventional benchmark of $2\times\text{CO}_2$, and if upper bound warming and damages are taken into account, and considering the range of estimates for abatement costs, then even a standard economic analysis using the social discounting approach outlined here can conclude that the benefits of aggressive action outweigh the costs on economic grounds (Cline, 1992). This result obtains even though technical progress permits future per capita incomes eventually to be much higher than present, because given conventional estimates of the elasticity of marginal utility, the intergenerational bargain of exchanging modest costs today for large avoided damages in the future remains attractive. In this case, the two considerations just noted simply reinforce this conclusion.

In many developing countries, Solow's definition would not be viewed as acceptable, since it seems to place no weight on their aspirations for growth and development. Further, formal models analyzing optimal development paths using a min-max (Rawlsian) criterion would, of course, focus exclusively on the welfare of the less developed countries in the first place (Note that in Rawls' formulation, $0 = \infty$). But the prescription would be simple: massive redistribution from the North to the South immediately, without introducing the complication of long-term environmental problems. Even if there were limits on the transfers, it would suggest that all of the costs of mitigation--including those occurring within the South-- be borne by the North.

Of course, even the utilitarian approach ($0 < \infty$) would tend to lead to higher general income transfers to poor countries than presently observed. Adherents of the descriptive approach would ask why the utilitarian construct is appropriate when considering intergenerational equity (as in the identification of the SRTP suggested in equation 4.1) if it is not applied in practice across (or, for that matter, within) countries at the present. In one sense, this

question is another application of the principle suggested above that in the absence of optimal redistribution intervention by the government, observed market rates (in this case of North-South transfers) will not necessarily or likely equal social rates. Alternatively, the equity norm suggested here may not be widely shared by governments or voters.

Some might seek to explain the paucity of present-day North-South transfers on grounds of incentive effects. Thus, the massive marginal tax rates on the North that would be required to equalize income levels with the South could seriously reduce the amount of output available for redistribution. Perhaps more relevant (in view of the modest but unfulfilled international targets for grant aid), the problems of still unaddressed poverty within the North and sharp inequality within many developing countries complicate attempts to improve overall welfare through North-South transfers. The fundamental explanation, however, is that each country tends to consider primarily the welfare of its own citizens, and only secondarily that of others.

Despite the political constraints on present-day North-South transfers that would otherwise be recommended by the utilitarian approach, the time-discounting concepts of that approach, and the SRTP in particular, remain valid subject to these constraints. Thus, consider a matrix with two rows -- North and South -- and two columns -- present and future. The SRTP can appropriately be applied between the two columns along each row, even if there is a barrier to its application between the two rows. Leaders and publics in developing countries have cause for concern about their descendants just as do their counterparts in developed countries. As noted above, however, the value of the SRTP is likely to be higher for the South row than for the North row.

At the same time, both the Rawlsian and utilitarian approaches imply that the South should actively engage in mitigation financed by transfers from the North, so that efficient mitigation can be obtained. Any Pareto efficient development path (including any reasonable definition of sustainable development) must have this property of efficient mitigation. Thus, the level of mitigation should be set based on the eventual target of greenhouse gas stabilization and implied levels of world emissions (without regard to where those emissions originate). The magnitudes of actions required to attain those levels of world emissions will, of course, depend on the rates of growth of the less developed countries as well as the increased energy efficiency among both the developed and developing countries.

Annex 4A
Methodological Notes on Discounting

4A.1 Intertemporal Maximization of Well-Being

In an influential series of articles, Koopmans (Koopmans, e.g., 1960) conducted a series of thought-experiments on intertemporal choice so as to see the implications of alternative sets of ethical assumptions in plausible worlds. He suggested that we can have no direct intuition about the validity of discounting future well-beings, unless we know something concrete about feasible development paths. Applying this approach, Mirrlees (1967) and Chakravarty (1969) showed that in plausible economic models for developing countries, not to discount future well-being could imply that the present generation be asked to save and invest around 50 per cent of gross national product -- a stiff requirement when GNP is low. Nonetheless, these models tended to assume high rates of return on capital (a constant 33 percent rate in Chakravarty, 1969) and to consider time periods of decades rather than centuries. It is unclear that their findings hold for the centuries-scale problem of climate change, in part because of the much lower likely average return to capital over this horizon.

Koopmans (1960) considered the set of feasible consumption paths (from the present to the indefinite future) and the corresponding set of welfare or "well-being" paths. These paths could then be ordered to select the optimum path of well-being, according to the criterion:

$$4A.1) z = \int_0^{\infty} W(c_t) e^{-\rho t} dt$$

where $\rho > 0$.

Correspondingly, the discount rate for the time path of consumption is:

$$4A.2) i_t = i(c_t) = \rho + \theta(c_t) [dc/dt]/c_t$$

where $\theta(c_t)$ is the elasticity of marginal well-being, or marginal utility, at time t (Arrow and Kurz, 1970). (Note that whereas the main text treats this term as a constant, it is explicitly considered to vary with the level of consumption in the treatment here.) Along a full optimum path, the consumption rate of discount equals the productivity of capital (i.e. the social rate of return on investment). This is the famous Ramsey Rule (Ramsey 1928).

A convenient form of W is that giving a constant elasticity of marginal utility, such as:

$$4A.3) W(c) = c^{-\theta}$$

As discussed in the text, the larger is the rate of pure time preference (ρ) the lower is the weight accorded to future generations' well-being relative to that of the present generation. Mirrlees's (1967) computations essentially introduced this sort of bias ($\rho > 0$) as a way of

countering the advantages to be enjoyed by future generations, should the productivity of capital and technological progress prove to be powerful engines of growth.

As noted in the text, a higher value of θ means greater emphasis on intergenerational equity. As $\theta \rightarrow \infty$, the well-being functional in 4A.1) resembles more and more the Rawlsian max-min principle; in the limit, optimal growth is zero.

In 4A.3), $W(c)$ has no minimum value. If $\rho = 0$, this ensures that very low consumption rates are penalized by the optimality criterion reflected in (4A.1). On the other hand, if ρ were positive, low consumption rates by generations sufficiently far in the future would not be penalized by (4A.1). This means that unless the economy is sufficiently productive, optimal consumption will tend to zero in the very long run. Dasgupta and Heal (1974) and Solow (1974a) showed in a model economy with exhaustible resources that optimal consumption declines to zero in the very long run if $\rho > 0$ and in the absence of technical change, but that it increases to infinity if $\rho = 0$.

It is in such examples that notions of sustainable development can offer some analytical guidance. If by sustainable development we mean that the chosen consumption path should never fall short of some stipulated, positive level, then it follows that the value of ρ would need to be adjusted downward in a suitable manner to ensure that the optimal consumption path meet the requirement. This was the substance of Solow's remark (see Solow, 1974b) that, in the economies of exhaustible resources the choice of ρ can be a matter of considerable moment.

So far an assumption underlying this discussion has been that well-being or utility has not been bounded. If we restrict well-being to be bounded, other results obtain, because of the mathematical properties of the space of bounded sequences. For such sequences present value calculations are not rich enough to capture all of the subtleties of evaluation of a utility stream. Instead, one has to add to the present value another term. Chichilnisky (1994) has suggested that the present value term represents the requirement that the future should not be a dictator over the present; and that the second term represents the requirement that the present should not be a dictator over the future. This second term will in general have the form of a long-term average. It could be approximated by minimum requirements for the long run stocks of environmental resources. This formulation attempts to account for both basic levels of human needs and limitations on total resources.

Resource Sourcing and the Consumption versus Investment Discount Rate

Sandmo and Dreze (1971) address the choice of the correct rate of discount to use in the public sector when there are distortions in the economy, e.g. in the form of taxes, which prevent the equalization of marginal rates of substitution and transformation in the private sector. Under certain assumptions, the corporate tax drives a wedge between the marginal rate of time preference of consumers and the marginal rate of transformation in private firms.

They find that for a closed economy:

$$4A.4) 1+r < 1+i < 1+r/(1-t)$$

where r is the consumer interest rate, t is the tax rate, and i is the public sector's discount rate. This rate should thus be a weighted average of the rate facing consumers and the tax-distorted rate used by firms. Since $1+r$ measures the marginal opportunity cost of transferring a unit of resources from private consumption, and since $1+r/(1-t)$ is the measure for transfers from private investment, a unit of resources transferred from the private to the public sector should be valued according to how much of it comes out of consumption and how much out of investment⁴.

The general approach taken throughout this chapter is to calculate impacts on consumption, and to find the appropriate discount factor for discounting those changes. We are, in effect, taking consumption as our *numeraire*. This is convenient and natural, but there are other ways of performing the calculations, using other numeraires. Using other numeraires, relative prices over time (discount factors) will differ from those associated with the consumption numeraire. The failure to recognize this is a great source of confusion in the discounting literature. Thus, as suggested in section 4.7, if environmental goods had been chosen as the numeraire, the discount rate could even have been negative. It is important to remember, however, that nothing substantive depends on the choice of numeraire.

By the same token, if for example systematic relationships exist between the outputs and inputs of a project and the total changes in consumption they induce, and if consumption changes over time, then instead of discounting total consumption impacts as the SRTP, one could calculate the direct impacts using another discount factor. The discussion above of the Sandmo-Dreze formulation is a case in point. These alternatives do not provide prescriptions, only alternative formulas for arriving at the same point.

The discrepancy between public evaluation of a marginal dollar to future generations, and individuals' own intertemporal evaluations can arise even in the case of very simple social welfare functions. Thus, assume that there is a utilitarian social welfare function, which simply adds up the utility of successive generations, and for simplicity, assume each generation lives for only two periods. The t generation's utility is represented by a utility function of the form:

$$4A.5) U^t(c^t_1, c^t_2)$$

where the first argument refers to consumption the first period of the individual's life, the second to consumption the second period. Then observed market rates of interest refer to how individuals are willing to trade off consumption over their own life. These may or may not bear a close correspondence to how society is willing to trade off consumption across generations. The former corresponds to u^t_2/u^t_1 , while the latter corresponds to u^{t+1}_1/u^t_1 .

If the government has engaged in optimal intertemporal redistribution and does not face constraints in imposing lump sum (i.e. nondistorting) taxes on each generation, then the two will be the same, and equal to the marginal rate of transformation (in production, i.e. the return to investment). But whenever either of these conditions is not satisfied, then market rates of interest facing consumers (measuring their own marginal rates of substitution) need bear no close relationship to society's marginal rate of substitution across generations. Diamond and Mirrlees (1970, 1971) show that if the only reason for the discrepancy between producer and consumer interest rates is optimally determined commodity taxes, and there are no after-tax profits, possibly because there is a 100% pure profits tax, then the government should use the producer rate of interest. Stiglitz and Dasgupta (1971) have shown that this result does not hold if either of these assumptions is dropped.

Under certain circumstances (in particular the existence of optimal intergenerational lump sum transfers), asymptotically the producer rate of interest will equal the pure rate of time preference of society. More generally, when the government must resort to distortionary taxes, not only is this not true, but the rates of discount employed may reflect distributional considerations (see Stiglitz 1985).

Endnotes

1. This approach ignores diversity of individuals within any generation, and is thus subject to Schelling's criticism. Other simplifying assumptions here include the use of a utilitarian social welfare function, the assumption of the same utility function for each generation, and no recognition of changes in leisure (or, alternatively, by the assumption that those impacts can be folded into a single consumption equivalent variable). The standard models further assume that the elasticity of marginal utility with respect to changes in consumption (0) is constant. Each of these assumptions could be lifted, complicating the analysis substantially. The major effect would be to make the variables ρ and θ depend on other, possibly endogenous, variables, rather than taking the simple form postulated here.

2. With a non-utilitarian social welfare function, social welfare may be written in the form, e.g.,

$$S = G(U(C)).$$

If $G = U$, then it is clear that the rate at which social marginal utility diminishes with increases in consumption may differ from the rate at which private marginal utility diminishes, so that evidence about the latter is only partially relevant for the former.

3. There is a strong consensus within the economics profession that individual's marginal utility is convex. The behavioral implications with respect to risk of the assumption that $U'' < 0$ are consistently rejected by the data (it would imply, in particular, that absolute risk aversion strongly increases with consumption).

4. For an open economy, the elasticity-adjusted rate on foreign loans also enters the calculus. However, for analysis of a global issue, this extension is probably inappropriate, as globally the economy is closed.

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**Intergovernmental Panel on Climate Change
Working Group III**

Chapter 3

Equity and Social Considerations

Lead Authors:

**Tariq Banuri, Karl Goran-Maler, Michael Grubb,
Harold K. Jacobson, and Farhana Yamin**

Summary

Equity and social considerations are central to discussions of steps to be taken to implement Framework Convention on Climate Change because widespread participation is essential if the objectives of the Convention are to be gained. This is why the concept of equity is so prominent in the Convention. Countries are unlikely to participate fully unless they perceive the arrangements to be equitable. This applies particularly to equity among regions and countries, but equity within countries, and associated social considerations, are also important influences upon what is possible and desirable. Mitigating and adapting to climate change will require actions on the part of individuals. Governments will find it easier to comply with international obligations if their citizens feel that the obligations and benefits of compliance are distributed among them equitably. And richer countries are unlikely to burden their poorer citizens to benefit relatively rich citizens in poor countries.

Scientific analyses cannot prescribe how social issues should be taken into consideration and how equity should be applied in implementing the Climate Convention, but analysis can clarify the implications of alternative choices and their ethical basis. There are a variety of meanings of equity and there are various principles that have been designed to achieve equity. On some issues different equity principles point to similar responses, suggesting clear guidance, while on others they may conflict. In either case, there is a need for judgment, drawing on concepts of equity.

Issues relating to equity among regions and countries stem from the substantial differences that exist among countries. Countries differ not only in terms of size, resources, population, and wealth, but also in terms of emissions of greenhouse gases, vulnerabilities to climate change, and institutional capabilities to respond effectively to climate change. There is no single method of aggregating these differences, or decision rule for dealing with them. The Framework Convention on Climate Change provides considerable guidance for applying the concept of equity so as to take account of the many differences among countries. However, the application of equity to specific circumstances will require further elaboration of the Convention's principles and obligations, many of which were designed to be ambiguous and remain so.

Equity issues involved in responding to climate change may be divided into four distinct categories:

- distributing the costs of adaptation;
- distributing future emissions rights;
- distributing the costs of abatement; and,
- ensuring institutional and procedural fairness.

The Framework Convention on Climate Change offers some guidance on all of these issues. It requires developed country Parties to take the lead in limiting their emissions whilst

recognizing that developing countries' emissions are relatively low and will need to grow to meet their legitimate social and developmental needs. It also requires developed country Parties to assist developing country Parties to cope with both the costs of abatement as well as the costs of adaptation to the adverse effects of climate change. Such assistance must be provided by the Convention's financial mechanism which must have "an equitable and balanced representation" and transparent governance to ensure procedural equity between donor and recipient country Parties.

This North-South focus is also apparent in much of literature, which seeks to clarify issues of equity between developed and developing countries much more than among developed countries. Since developed countries have obligations under the treaty to take immediate action, this is a serious lacunae. There are however a variety of specific analyses that propose schemes for distributing costs of coping and abatement and emission rights, and analyze the distributional effects of these schemes, across the range of countries.

Social considerations, and the experience of the implementation of structural adjustment policies, point to the need to consider and target for special consideration specific groups. Countries (such as island and other low-lying states, or drylands) and special groups within society (such as the poor, and sometimes women or children, or specific occupations or regions) that are especially vulnerable to climate change--those on whom the costs of abatement and coping would be especially burdensome--merit special attention.

Concern about equity and social impacts points to the need to strengthen institutional capacities, particularly in developing countries, to make and implement collective decisions in a legitimate and equitable manner. These institutional capacities surely include developing resources to analyze equity and social issues.

Institutional weaknesses also inhibit the ability of developing countries to participate effectively in international negotiations. Assistance to help these countries develop a greater capacity to assimilate and analyze information and proposals, and to participate effectively in international discussions, would increase the prospects for achieving effective, lasting and equitable agreements on how best to address the threat of climate change.

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Intergovernmental Panel on Climate Change
Working Group III

Chapter 3

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Table of Contents

46		
47		
48		
49		
50		
51		
52		
53		
54		
55		
56		
57		
58		
59		
60		
61		
62		
63		
64		
65	I INTRODUCTION	4
66	I.1 THE ROLE OF EQUITY	4
67	I.2 CONCEPTS OF EQUITY	5
68	I.3 UTILITY, EQUITY, AND ECONOMIC EFFICIENCY	8
69	II EQUITY IN INTERNATIONAL LAW AND IN THE FRAMEWORK CONVENTION	10
70	III PRINCIPAL DIFFERENCES AMONG REGIONS AND COUNTRIES	19
71	III.1 INTRODUCTION	19
72	III.2 WEALTH AND CONSUMPTION	19
73	III.3 PATTERNS OF GREENHOUSE GAS EMISSIONS	21
74	III.3.a Historical and cumulative emissions	22
75	III.3.b Current emissions	25
76	III.3.c Future emissions	26
77	III.4 VULNERABILITY TO CLIMATE CHANGE	27
78	III.5 SOCIAL CONSIDERATIONS	28
79	III.6 DIFFERING RESOURCE ENDOWMENTS	31
80	III.7 CONCLUSIONS	31
81	IV DISTRIBUTING THE COSTS OF COPING: IMPACTS, RISKS AND INTERNATIONAL	
82	INSURANCE	33
83	IV.1 NATURE OF IMPACTS AND UNCERTAINTIES	33
84	IV.2 PAYING FOR THE COSTS OF COPING	34
85	IV.3 SHARING RISKS	35
86	IV.4 POLICY IMPLICATIONS	38
87	V DISTRIBUTING FUTURE EMISSIONS AND ABATEMENT COSTS	43
88	V.1 INTRODUCTION	43
89	V.2 PRINCIPLES FOR SHORTER-TERM ACTION	43
90	V.3 LONGER-TERM ALLOCATION: UNDERLYING PRINCIPLES	45

91	V.4 SPECIFIC EMISSIONS ALLOCATION PROPOSALS	48
92	V.5 PROPOSALS FOR DISTRIBUTING ABATEMENT COSTS INCLUDING INTERNATIONAL TRANSFERS	51
93	V.5.a Basis of the Climate Convention	51
94	V.5.b Transfers determined by emission allocation and tradable entitlements	52
95	V.5.c Direct payment accountability approaches	53
96	V.6 INTERNATIONAL TRADE AND THE INCIDENCE OF ABATEMENT COSTS	57
97	V.7 NORTH-SOUTH JOINT IMPLEMENTATION	58
98	VI EQUITY WITHIN COUNTRIES	61
99	VI.1 INTRODUCTION	61
100	VI.2 POLICY ORIENTED LITERATURE	62
101	VI.3 INSTITUTION ORIENTED LITERATURE	65
102	VI.4 THE QUESTION OF ETHICS	68
103	VII PROCEDURAL FAIRNESS IN INTERNATIONAL CLIMATE CHANGE PROCESSES	70
104	VII.1 INTRODUCTION	70
105	VII.2 PARTICIPATION	71
106	VII.3 INFORMATION	72
107	VII.4 LINKS BETWEEN INTERNAL AND INTERNATIONAL PROCESSES	73
108	VIII CONCLUSIONS	74
109		

Intergovernmental Panel on Climate Change
Working Group III

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I Introduction

The first principle in Article 3 of the Framework Convention on Climate Change states:

"1. The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof."

Because of its inclusion in this principle equity must be a key consideration in all actions taken under the Convention. In common language equity means "the quality of being fair or impartial," or "something that is fair and just." (Flexner, 1987, pp. 656-657)

Science cannot prescribe or decide what would be equitable actions under the Climate Convention. This is the task of the Parties to the Convention. Science, religion, and philosophy can, however, illuminate the meaning of equity and clarify the choices that the Parties face. This is the task of this chapter. It considers concepts of equity and issues that must be considered in efforts to apply these concepts. It then views these broad concepts within the tradition of international law and the specific context of the Framework Convention, and considers the several ways in which this text assigns specific meaning to equity. It next analyzes in detail several specific aspects of equity: international equity in coping with the impacts of climate change and associated risks; international equity in efforts to limit climate change; equity and social considerations within countries; and equity in international processes. Equity among generations (or intergenerational equity) is the subject of the next chapter. Social considerations enter into the discussions of equity in all of the sections.

1.1 The role of Equity

In considering equity issues it is useful to make several points at the outset. No international agreement has ever been founded purely on a logical consideration of equity issues; a whole range of other factors, ranging from basic economic and political power structures to accidents of timing and personalities, influence the outcome. Yet nor is the

converse--the cynical view that equity considerations play no role at all in the real world of international politics--true. A broad view of self-interest often points towards explicit consideration of equitable outcomes because of the longer-term risks that grossly inequitable behaviour may pose to stability and cooperation in the international system.

This analysis focuses upon the equity issues relating to climate change responses that might be considered by the international community. There are many more general issues associated with environmental ethics and values, that have attracted a substantial body of literature. Also there are many inequities in the world, among and within countries, the subject of long international discourse and analysis. It is no more realistic to suppose that climate change can be a vehicle to resolve all the international inequities than to suppose that it can resolve all the inequities within countries--but there is an important difference. Within countries, institutions exist to address a wide range of issues of common interest to members of that society. The institutions have developed in part to provide a way of taking decisions about constitutes acceptable behaviour, and decisions about the distribution of wealth and resources--in most countries, through regulation of market structures backed by legal codes and with taxation as a way of redistributing resources to help provide social goods.

Equity--in the form of views about what constitutes justice--is an important influence and measure of the legitimacy of these institutions and their decisions. The actual strength and perceived legitimacy of these institutions varies widely, but policies to address climate change at the level of national implementation fall within the remit of national institutions and accepted processes. By contrast, institutional parallels at the international level are relatively weak. In responding to climate change, the international community faces unavoidable decisions about the distribution of effort and burdens, and what constitutes acceptable behaviour, in circumstances where the internal activities of one state may directly impact upon all others. Whilst on a modest scale there are precedents, climate change is wholly unique in the scale and scope of its potential implications and the coordinated international response it requires. Yet international institutions dedicated to coordinating such a response are relatively new (such as the IPCC) or in the process of being established as a result of the Framework Convention on Climate Change. Consequently, examination of international equity issues is relatively recent and may need greater explicit analysis and consideration by international institutions if these are to support the international community's response to climate change. Climate change, and strategies for responding to it, will also have implications for equity within countries that should be considered.

1.2 Concepts of Equity

Since Confucius, Plato, Aristotle, and the Vedantic texts, theorists who have dealt throughout the ages with economic, political, and social issues have developed and explored concepts of equity. Several broad points emerge from this extensive literature. The first is that equity applies to two separate categories of issues. It applies to both procedural issues--how decisions are made--and consequentialist issues--the outcomes of decisions.

One prominent view of procedural equity is that it mandates equal treatment before the law. Similar cases must be dealt with in a similar manner. Exceptions must be made on a principled basis. In this sense, the principle of equity not only requires that law should govern decisions but also provides guidance in how laws should be applied. All of the circumstances in which a law would be applied cannot be foreseen at the time of its formulation. Starting with Aristotle, theorists have argued that laws be applied in an equitable manner to achieve what the legislators would have intended in the specific circumstances of a particular case (Shapiro, 1990, p. 220). The concept of equity also embodies a higher notion of justice that goes beyond the rules no matter how fairly they were devised. The Anglo-American common law tradition, for example, often introduces equity into judicial decisions to correct a potential injustice by too rigid an application of the law.

The principle of equal treatment before the law is closely allied to notions of basic, minimum rights for individuals. Securing these rights is central to a number of conceptions about procedural equity. For instance, John Rawls (1971) has argued that all individuals have equal rights to the most extensive system of equal political liberties compatible with a similar system of liberty for everyone else. A similar but stronger view has been put forward by Robert Nozick (1974) who has argued that all individuals have a sphere of moral rights in which no one, including the state, is allowed to interfere, irrespective of the consequences for well-being from such interference. These theories shed some light on how their conception of procedural equity can be achieved.

It is important to recognize that these particular theories were originally developed for dealing with questions of justice within a state. Rawls, for instance, draws a sharp distinction between the principles of justice that prevail among persons within a society and "justice between states" to which his theory was not intended to apply (Stone, 1993). The application of these theories to the subject of international justice--justice between states--presents problems (Van Dyke, 1975, Stone, 1993). Not least is the fact that as holders of the rights of sovereignty, it is nation-states, rather than individual human beings, that dominate international society.

Nevertheless, by extrapolation and analogy, these theories offer insights about the application of procedural equity as between states. For example, the notion that procedural equity demands that basic rights (of individuals or states), however they are defined, must be respected in decision-making is commonly accepted in domestic and international law. Article 2, paragraph 7 of the UN Charter, for instance, states that nothing contained in the Charter shall authorize the United Nations to intervene in matters which are essentially within the domestic jurisdiction of any state, but that the principle should not prejudice the application of enforcement measures. Other elements of procedural equity between states are discussed in more detail in the next section on international law.

Consequentialist equity has to do with the outcome of decisions, particularly the distribution of burdens and the allocation of benefits. There are several broad traditions defining the meaning of equity in this sense (Young, 1994). They may be summarized in the

following categories: parity, proportionality, priority, classical utilitarianism, and Rawlsian distributive justice.

Parity is a formula for equal distribution of burdens or benefits. Parity demands that all claimants receive equal shares; it is closely associated with egalitarianism.

Proportionality is a principle which dates back at least to Aristotle; it asserts that burdens or benefits should be distributed in proportion to the contributions of claimants.

Priority argues that those with the greatest need should be advantaged; this forms the basis of the "basic needs" approach which puts the emphasis on the absolute right of individuals to goods and services necessary to sustain their lives at some minimum standard of well-being making it worth living. This would include potable water, minimum nutrition, and health care and general environmental resources.

Classic utilitarianism proposes that burdens and benefits should be distributed so as to achieve the greatest good for the greatest number. This Benthanite formula can be expressed mathematically in terms of maximizing total utility, which of course requires the measurement and comparison of utilities, an issue which will be considered below.

Rawlsian distributive justice (Rawls (1971)) carried the concept of utilitarianism a step further, arguing for an equal distribution unless an unequal distribution operates to the benefit of the least advantaged. It therefore requires that deviations from equality should benefit the least advantaged.

No society has ever had complete consensus on any one of these approaches alone as an adequate criterion for defining consequentialist equity. Some (such as basic needs) are incomplete, prohibiting certain outcomes but not helping choices between other alternatives. Single principles may also not be appropriate or practical as the only standard, because among other reasons, cases and individuals are rarely identical and burdens and benefits may not be divisible, or if they are they may not be divisible into shares that are susceptible to precise, cardinal measurement so that it is impossible to apply the principles directly.

In practice, when societies try to achieve equity, they do so in nuanced and subtle ways, applying several criteria and seeking to achieve a balance among them. The balance is also affected by self-interest; in the real world, people tend to seek for and emphasize principles that may advantage them. Nevertheless, the principles are useful guides to what might constitute equitable decisions. Illustrating the likely consequences of their application may clarify the choices that have to be made in seeking equitable solutions as in the implementation of the Framework Convention on Climate Change.

The theme of there being different and sometimes conflicting principles, and the need for compromise between them, is extended by Rayner (1994), who argues that a number of fundamentally different "world views" are adopted towards climate change. These views span not only different ideas of equity but also differ concerning basic assumptions about the

urgency of abatement action and appropriate management strategies, and can be correlated with different institutional types identified by cultural theory.¹ The process of developing a response is seen as a process of compromise between these different world views, each of which tries to influence policy to correspond more closely to its own perceptions--perceptions which again tend to be influenced by interests.

1.3 Utility, equity, and economic efficiency

Welfare economics is based upon utilitarianism. It requires some measure of welfare (utility), as a function of various factors that can determine the welfare of an individual: for example, the amount of goods and services that the individual can access, different aspects of the physical and spiritual environment, and rights and liberties. The idea of a 'utility function' is to aggregate a rather long list of factors affecting individual well-being into one single measure of welfare. There remains the much more difficult task of aggregating these utilities over different individuals. In a sense, this is the real ethical problem in connection with climate change.

There is no inherent conflict between economics and equity, as some people assert; but it can arise because of differing ideas or assumptions, sometimes hidden, about how individual utilities should be defined, compared and aggregated. It is important to understand that economics itself cannot determine this question. Explicit discussions of equity are essential because they reflect differing ideas about how--and indeed whether--individual utilities should be measured and aggregated.

Arrow (1951) addressed the fundamental question whether individual preferences--irrespective of what they look like--can be aggregated in a reasonable way into overall societal preferences. He concluded that in general it is impossible to aggregate individual preferences to a social welfare function if we require that the aggregation should satisfy some very natural and reasonable conditions, including that no individual should be allowed to be a dictator. Thus, it is in general not possible to deduce "objectively" a socially preferred distribution of well-being from individual preferences. However, if it is known that individual preferences are restricted to certain types, then it may still be possible to aggregate individual preferences in a consistent and reasonable way to form a social ordering (see Sen 1987).

It can be argued that there is a rough consensus on what constitutes an equitable distribution of welfare over time. This is so because of the apparent agreement on the concept of sustainable development, as introduced by the World Conservation Strategy (IUCN 1980) and popularized after The World Commission on Environment and Development--the Bruntland Commission--published its report *Our Common Future* (1987). The central idea behind the concept of sustainable development is that the present generation should not make changes that reduce the possibilities for future generations to achieve comparable well-being. The concept of sustainable development has received widespread support from all states as evidenced by its inclusion in, for example, the Rio Declaration, Agenda 21. It is specifically mentioned in paragraph 5 of Article 3 of the Framework Convention on Climate Change. Despite its widespread acceptance, the precise meaning of the concept is not universally agreed

and as a result, its application is not straightforward. Issues of intertemporal justice, especially implications in terms of the "discount rate" used to value future impacts, are discussed primarily in the next chapter.

The comparison and aggregation of utilities across different countries and across different individuals is much more contentious. The GNP indicator avoids this by focusing simply upon the total measured consumption in a country; in principle, it lays no claim to represent welfare directly, nor does it claim that aggregating GNP across different countries is a valid measure of global welfare. In practice however, maximizing GNP does often become a primary focus of policy and economic analysis. This implicitly embodies an assumption either that a given amount of additional wealth is equally valuable to everyone; or that the additional welfare can and will be redistributed so as to fulfill some more explicit measure of aggregate social welfare. The latter is achieved by a balance between the focus upon GNP and the establishment of institutions and processes charged with redistribution, social protection and provision of various social goods.

Internationally, as noted, such processes and institutions are weak or non-existent. Hence the debate about whether and how to compare national utilities internationally is central. Views range from asserting that countries should act as if they value all countries equally (i.e. assume equivalent utility functions and aggregate all with the same weight), to asserting that utilities can and should not be estimated and aggregated at all across countries, so that countries bear no responsibility for impacts on others. International negotiations are to an extent about trying to reach a compromise between these two extremes, especially concerning policy on issues where the activities of one country may directly affect another - like climate change.

It is in this issue of whether and how to aggregate separate utilities that debate about apparent conflict between equity and economic efficiency can arise. Really it all depends upon how efficiency is defined. "Pareto efficiency" is a modest goal, namely that of seeking a situation in which no-one can be made better off without making anyone else worse off. Pareto efficiency is thus generally neutral with respect to equity because it allows an infinite variety of possible distributions. More often however, the term 'economic efficiency' is used in terms of seeking to maximize 'something' with the resources available. Maximizing GNP--or perhaps 'Gross World Product'--could involve highly inequitable outcomes. Seeking to maximize some explicit measure of aggregate welfare--which requires defining a social welfare function--may result in a very different concept of "efficiency"--and a very different "optimal" outcome.

Whether there is any inherent conflict between equity and efficiency therefore depends entirely upon how "efficiency" is defined, in terms of what we are trying to maximize. Equity is thus essential to climate change discussions because there is no consensus about whether and how to measure and aggregate welfare within and, still less, between countries. On the contrary, there are fiercely competing views grounded in differing interests and philosophies. The objective--and hence the optimal policy--is thus inherently a matter for debate, negotiation and compromise between conflicting interests and ethical philosophies.

II. Equity in International Law and in the Framework Convention

International law and the Framework Convention on Climate Change both provide a context for efforts to apply principles of equity in implementing the convention. This section examines how the basic rights and obligations of states established under international law, through treaties, custom, the general principles of law, and judgments and awards of courts and international tribunals, provide a framework for consideration of issues concerning procedural and distributive equity.² In addition to the general rules and principles of international law, the UN Framework Convention on Climate Change contains principles and specific provisions concerning equity. These provisions have important implications for the implementation of the Convention, including for the elaboration of further commitments and mechanisms for burden sharing on an equitable basis.

International Framework

One of the basic tenet of international law is the sovereign equality of all states. Each state has jurisdiction over its territory and has the right freely to choose and develop its political, social, economic and cultural systems, including the right to develop its own policies and laws regulating the exploitation of its natural resources. As a corollary to these principles, each state has a duty to refrain from threatening the territorial integrity of another and the obligation not to intervene in matters within the domestic jurisdiction of any other state.

Principle 2 of the Rio Declaration on Environment and Development states:

States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their environmental and developmental policies, and the responsibility to ensure that activities within their own jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.³

Each state may devise its own climate change policies and programs. Accordingly, the extent to which national measures are equitable in allocating costs and benefits among various regions, economic sectors, social groups or individuals within its territory, is primarily a domestic matter. The allocation of responsibilities for mitigation and adaptation, and mechanisms to implement these, as between states is however, an international matter and subject to the general rules and principles of international law and for states that are Parties, to the specific provisions of the Framework Convention on Climate Change concerning equity. It is important therefore to understand the meaning of equity in international law, in particular what factors have been included in the concept of equity and their practical procedural and distributive consequences.

The concept of equity

The International Court of Justice (ICJ) explained the legal nature of equity in its judgment on the 1982 Continental Shelf Case (Tunisia/Libya).⁴ It stated:

Equity as a legal concept is a direct emanation of the idea of justice. The Court whose task is by definition to administer justice is bound to apply it.⁵

The Court explained that "the legal concept of equity is a general principal directly applicable as law."⁶ This means that equity can be a source of law as well as consisting of considerations necessary for the sensible application of the law.⁷ In its 1982 Judgment, the Court recognized that equity was relevant when the Court was called upon to apply international law and found that it could choose among several possible interpretations of the law. The Court interpreted this as meaning not that it could fashion new law but that when it could choose among several interpretations of the law it was bound to choose the interpretation "which appears, in the light of the circumstances of the case, to be the closest to requirements of justice".⁸ The Court explained that in international law the application of equity consists of the application of equitable principles to achieve an equitable result taking into account all the legal and factual circumstances relevant to the case in hand.⁹

This concept of equity encompasses both procedural and distributive elements which means that from a legal perspective, the application of equity cannot be generalized as principles and factors relevant to the application of equity to one context cannot necessarily be transposed and applied in another. The following examination of equity in different international environmental contexts is intended to provide background information about the role of equity in benefit and burden sharing arrangements between states concerning access to and use of natural resources. The legal insights and practical experience gained by states and the ICJ in dealing with equity in these contexts may be relevant for climate change.

Continental shelf

The ICJ has examined the role of equity in a series of cases concerning rights of access and use of the continental shelf between states. In a dispute between Malta and Libya the Court said that the concept of equity included the principle of good faith negotiations to resolve disputes between parties.¹⁰ This highlights the important procedural components of the concept of equity which also include:

"the principle of respect due to all such relevant circumstances [and] the principle that although all States are equal before the law and are entitled to equal treatment."¹¹

As far as distributive equity is concerned it went on to declare that the application of equitable principles cannot be used for "refashioning geography or compensating for the

inequalities of nature ¹² The Court pointed out that so far as the relevant law concerning continental shelf delimitation is concerned,

"equity does not necessarily imply equality ... nor does it seek to make equal what nature has made unequal."¹³

The Court also went on to state that equity includes "the principle that there can be no question of distributive justice."¹⁴ Accordingly, in that case the Court rejected Malta's claim to a greater share of continental shelf based on its argument that it was resource poor and had greater socio-economic and developmental needs than oil-rich Libya.¹⁵ In a recent ICJ case concerning between Norway and Denmark, the Court again considered the relevance of socio-economic factors, including population, and rejected these as relevant in determining a state's entitlement to continental shelf resources.¹⁶ In a case between the USA and Canada, however, the Court indicated that where the overall result might entail "disastrous repercussions on the subsistence and economic development of the populations concerned," it may be inequitable to not take this into account.¹⁷

It is not possible to derive general conclusions about equity from the foregoing as the Court has stressed that each case must be examined in the light of its legal and factual circumstances. What this body of law does make clear, however, is that the Court has not yet had to deal with interpreting obligations that are related to or conditional upon the consideration of complex factors such as socio-economic development or the needs of the present and future populations. Moreover a closer reading of these cases illustrates the Court's reluctance to use equity as a basis to achieve distributive justice on a wider scale. This suggests that, in the absence of clear legal rules requiring the consideration of factors such as socio-economic development and population, the ICJ may not necessarily regard them as relevant or of paramount importance in other contexts where disputes concerning access to and use of natural resources raise wide-ranging distributive justice concerns.

This may have significant legal and practical consequences in the climate change context where implementation of a range of Parties' obligations under the Convention is conditional upon taking into account their socio-economic development, national needs and wide-ranging list of geographical factors. It is also particularly important in the context of negotiating future greenhouse gas emission reductions or devising a joint implementation systems as both raise fundamental distributive questions about the basis on which countries are entitled to continue their emissions.

The role of equity in the legal regime established for the deep seabed in Part XI of the 1982 United Nations Conference on the Law of the Sea (UNCLOS) differs markedly from principles and rules concerning the continental shelf. UNCLOS aims at distributing the benefits of exploitation as widely as possible, because it incorporates a notion of equity that includes a substantial element of distributive justice.¹⁸ The equitable principle that inspires this regime is that the Area (the deep seabed) and its resources are the "common heritage of mankind."¹⁹ Article 140 provides, for example, that activities in the Area "shall be carried out for the benefit of mankind as a whole, irrespective of the geographical location of States,

whether coastal or land-locked, and taking into particular consideration the interests and needs of developing States and of people who have not attained full independence..."

Unlike the law on continental shelf delimitation, these provisions expressly call for the consideration of socio-economic factors and economic needs, particularly of developing countries or other States disadvantaged by geography, to be taken into account in apportioning benefits. No definition of equity was included in UNCLOS. To give effect to these provisions, Parties to UNCLOS may have to elaborate equitable sharing criteria to distribute any financial and other benefits arising from the Area which may have implications for the climate change context.

Perhaps the clearest international example for the application of equity is the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer which arose as a result of the 1985 Vienna Convention for the Protection of the Ozone Layer. Many developing countries had argued that, in view of their marginal contribution to the ozone problem, limited financial resources and more pressing developmental concerns, they should not be expected to take on the same commitments as richer, developed countries whose emissions had caused the ozone problem.²⁰ Participation in the Montreal Protocol of a large number of developing country Parties is widely viewed as a measure of its success in addressing fairness or equity concerns of developing countries and also for balancing environmental needs with economic imperatives and flexibility for industrial producers of ozone depleting substances.

It is the use of innovative legal techniques to implement these equitable concerns that distinguishes the Montreal Protocol from other conventions. The following list provides a brief outline of the way in which the Protocol's substantive provisions give practical expression to equity concerns. These "equitable" techniques include:

- differentiated standards for developed and developing country Parties including provision of grace periods for compliance for the latter; allowing increased developed country Party production to enable developing country Parties to meet their "basic domestic needs"; and allowing developing countries to base their emission entitlements on a per capita basis;
- financial assistance to developing countries, over and above overseas development assistance, to cover "all agreed incremental costs" and enable compliance;
- transfer of technology, especially of best available, environmentally safer substitutes under fair and most favorable conditions, facilitated by the Protocol's financial resources if necessary;
- limited operation of a tradable permit or joint implementation scheme to achieve "industrial rationalization" to minimize economic disruption and provide flexibility to producers of ozone depleting substances and

- an acknowledgment that developing countries' abilities to comply is conditional upon the "effective implementation" of developed countries' financial cooperation and technology transfer obligations.

As a result of its success in attracting developing country Parties, the Montreal Protocol approach was extensively discussed as a "model" for the Framework Convention on Climate Change.²¹

What is the role of equity in the Framework Convention on Climate Change so far as rights and responsibilities to protect the climate system are concerned? Unlike the Montreal Protocol which mentions equity only once in the Preamble, the Climate Convention includes refers to equity three times in its substantive provisions. As was mentioned in the opening paragraph of this chapter, the Convention specifically mentions "equity" in Article 3.1 concerning principles by stating that:

"The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof."

This principle, which is intended to "guide" Parties in implementing all the provisions of the Convention mentions equity in the context of burden sharing between all Parties, in particular, as between developed and developing country Parties. It also mentions future generations suggesting that equity requires consideration of the responsibilities of present generations to future ones as part of burden sharing arrangements.

Equity also appears in Article 4.2(a) which requires developed country Parties to commit themselves to:

"... adopt national policies and take corresponding measures on the mitigation of climate change These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in anthropogenic emissions consistent with the objective of the Convention, . . . taking into account the differences in these Parties' starting points and approaches, economic structures, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding that objective".

The reference to the term "equitable" concerning the specific commitments of developed country Parties concerns burden-sharing as between these Parties reflecting Parties' intention that equity should be applied not only between developed and developing countries, but among developed countries as well.

Finally, Article 11.2 requires the Convention's financial mechanism to:

"have an equitable and balanced representation of all Parties within a transparent system of governance."

Equity in this context appears to reflect developing country concerns. These concerns are of an essentially procedural nature reflecting the fact that the implementation of procedural elements may be essential for guaranteeing distributive outcomes that are perceived to be equitable.

What then is the significance of equity in the Convention and what practical consequences flow from its mention? It is clear that the application of "equity" in these contexts is intended to respond to quite different concerns. Equity cannot therefore have one meaning as its meaning will depend on the legal and factual circumstances of particular situations. Particular disputes will themselves depend on the interpretation of the nature and extent of Parties' obligations under the Convention. International legal rules on interpretation provide that "[a] treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose."²² For the purposes of interpretation, the context includes the preamble and any annexes.

The terms "equity" and "equitable" in the Framework Convention on Climate Change are closely related to its virtually all of its other substantive provisions. Accordingly, these terms must be interpreted in the light of the Convention's overall objective, approach and context. This task is made more complex by the fact that the Convention itself requires Parties to use the principles contained in Article 3 to achieve its objectives and guide implementation of its provisions. Equity is mentioned in the context of Article 3.1, which concerns the principle of common but differentiated responsibilities for the climate system which the Preamble states is a "common concern of humankind". This is however, only one of the five principles found in Article 3. Other principles include: the right to promote sustainable development; the precautionary principle; the need to take into account the specific needs and special circumstances of developing country and vulnerable Parties; and commitment to promote a supportive and open international economic system.

The meaning of much of these complex principles, including concepts such as "common concern of humankind," remain open to interpretation. It is clear however, that these interlocking concepts and principles bound the way in which Parties' obligations can be interpreted and in which equity can be applied in a particular case. The application of equity is also bounded by the structure of differentiated commitments set up by the Convention. Like the Montreal Protocol, the Convention requires developing country Parties to accept a smaller share of the global burden of combating climate change in view of their smaller contribution to the problem and their limited financial capabilities.

The differentiated set of commitments, set out in Articles 4.1 - 4.5 of the Convention, distinguish between developed and developing country Parties and those with "an economy in

638 transition." All developed country Parties, including those with economies in transition,
 639 (countries listed in Annex I of the FCCC, or Annex 1 countries²³ are required to take the lead
 640 in mitigating climate change (Article 4.2 (a)). These parties:

641
 642 " . . . may implement such policies and measures jointly with other Parties and
 643 may assist other Parties in contributing to the achievement of the objective of
 644 the Convention. . . ." Thus joint implementation (JI) is possible, and could be
 645 seen as a vehicle for transfer of resources.

646
 647 Developed country parties and other developed parties listed in Annex II of the FCCC (the
 648 European Union and the member countries of the Organization of Economic Cooperation and
 649 Development) are obligated to assist developing country Parties vulnerable to the adverse
 650 effects of climate change meet the costs of adaptation (Article 4.4). They must transfer
 651 technology and financial resources to developing countries to enable the latter to implement
 652 their more limited commitments to combat climate change (Article 4.5). In view of their
 653 limited financial resources, Parties with economies in transition however, are not obligated to
 654 provide such assistance. In discussing the obligations

655
 656 Articles 4.6 - 4.10 provide a range of factual or other circumstances that must be given
 657 consideration so far as implementation of Parties' differentiated commitments are concerned.
 658 These Articles are therefore of particular relevance in considering what factors might or might
 659 not count as a relevant "equitable factors" in a particular case where implementation of
 660 commitments is in question.

661
 662 For example, Article 4.6 provides that a certain amount of "flexibility" must be given
 663 to Parties with economies in transition in the implementation of their Article 4.2 (a)
 664 obligations. Article 4.7 makes the implementation of developing country Parties commitments
 665 conditional on the implementation by developed country Parties of their financial and
 666 technology transfer commitments and recognizes that

667
 668 " . . . economic and social development and poverty eradication are the first and
 669 overriding priorities of the developing country Parties."

670
 671 Article 4.8 provides that Parties are required to give full consideration to the specific
 672 needs and concerns of the developing country Parties with the special features referred in (a) -
 673 (i) of this Article. These features include for example, geographical, biological and economic
 674 factors such as whether a country is small island, is prone to natural disasters or
 675 desertification, or highly dependent on income from fossil fuel consumption or production.
 676 Article 4.9 provides that full account must be taken of least developed countries for funding
 677 and technology transfer. Finally, Article 4.10 provides that consideration should be given to
 678 all Parties whose economies are highly dependent on income generated from the production or
 679 consumption of fossil fuels or energy intensive products and for which Parties have serious
 680 difficulties in switching to alternatives.

681
 682 Several other sections of the Framework Convention, though they do not specifically
 683 mention equity, are relevant to ways in which equity should be interpreted. The broad
 684 statement of the Convention's objective in Article 2 states the goal of stabilizing greenhouse
 685 gas concentrations at a level "that would prevent dangerous interference with the climate
 686 system." It then goes on to specify a time-frame within which this objective should be
 687 achieved.

688
 689 "Such a level should be achieved within a time-frame sufficient to allow ecosystems
 690 to adapt naturally to climate change, to ensure that food production is not
 691 threatened and to enable economic development to proceed in as sustainable
 692 manner."

693
 694 This stricture bounds the way in which equity should be achieved.

695
 696 In other words, equity is to be achieved in ways that allow all Parties continued economic
 697 growth and international trade is to be an essential instrument in this growth. Strategies are to
 698 be tailored to the specific conditions of Parties.

699
 700 The preamble of the Framework Convention on Climate Change singles out several
 701 categories of Parties for special consideration, thus broadly defining how the concept of equity
 702 should be applied. One perambulator paragraph notes the particular vulnerability of: small
 703 island and low-lying countries; countries with low-lying coastal areas; countries with arid and
 704 semi-arid areas; those that are liable to floods, drought and desertification; and those that have
 705 fragile mountainous ecosystems. Another preambular paragraph acknowledges the special
 706 difficulties that will be faced by developing countries that have economies that are particularly
 707 dependent on the production, use, and exportation of fossil fuels as a consequence of limiting
 708 greenhouse gas emissions. While these preambular paragraphs do not create specific legal
 709 obligations they were intended to condition the way that the treaty is interpreted and
 710 implemented.

711
 712 By differentiating obligations and by including the foregoing factors the Framework
 713 Convention on Climate Change appears to have dealt comprehensively with the equity
 714 concerns. On a practical level however, the implementation of the Convention on an equitable
 715 basis will require further agreement between Parties about the significance of these factors, the
 716 relative weight to be given to each in particular situations and the precise meaning of
 717 commitments undertaken by each of them. This in turn will require agreement about the
 718 meaning of principles such as the principle of common but differentiated responsibilities, the
 719 right to sustainable development and concepts such as "common concern of humankind" as this
 720 is a new concept in international law. Reaching agreement about these matters will be a
 721 critical bearing on the allocation of benefits and burdens of combating climate change between
 722 states.

723
 724 The continental shelf cases and the general rules of international law concerning
 725 procedural equity suggest that states enter in to good faith negotiations to resolve differences of

726 views about access to and use of natural resources. Further negotiations between Parties to the
 727 Framework Convention on Climate Change would certainly assist the implementation of the
 728 Convention on an equitable basis. To the extent Parties do not enter into such negotiations or
 729 where disagreements persist, the general rules and principles of international law will remain
 730 relevant to resolving disputes about equity.

731 **III. Principal differences among regions and countries**

732

733 **III.1 Introduction**

734 Equity is not the same thing as equality, but issues of international equity are clearly
 735 related to a variety of differences between countries. This section summarises ways in which
 736 countries differ that are relevant to the question of equity between countries in responding to
 737 climate change. Subsequent sections then review some of the issues and conclusions that
 738 writers have drawn concerning implications for policy towards climate change.

- 739 • Five main dimensions of difference are cited in the literature: Wealth and
 740 consumption
- 741 • Emissions - past, present and future
- 742 • Impacts - the distribution of and vulnerability to climate change
- 743 • Social considerations and institutional capabilities
- 744 • Endowment with resources that may be affected by responses to climate change

745 This section of the chapter looks at the first two of these in turn and then considers the other
 746 three, which are addressed more fully elsewhere in the report, together.

747 **III.2 Wealth and consumption**

748

749 Wealth is one of the most obvious and pervasive differences between countries. Much
 750 of the literature on international equity starts from this issue, and the statistics need little
 751 elaboration. More than half of the world's population (58.7 percent) live in the forty-two
 752 countries that are classified as "low income" in the World Bank's *World Development Report*
 753 *1994* (World Bank, 1994, p. 162). These countries have an average per capita gross national
 754 product (GNP) of \$390. The 15.2 percent of the world's population that live in the twenty-
 755 three countries that the World Development Report classifies as "high income economies"
 756 have an average per capita GNP of \$22,160, almost *sixty times* that of the low income
 757 economies; the remaining sixty-seven "middle-income economies" have an average per capita
 758 GNP of \$2,490, just slightly more than one tenth that of the that "high income" countries.
 759 The discrepancies are smaller in terms of purchasing power--but are still very large.

760

761 These differences have a direct bearing upon the issue of climate change in various
 762 ways. Activities of the poor that result in emissions of greenhouse gases are mostly those that
 763 relate most closely to "basic needs," often at little more than subsistence levels--energy for
 764 cooking or keeping tolerably warm, emissions from agricultural activities, perhaps energy for
 765 light to enable reading, and occasionally for travel by public transport. Emissions from the

rich tend to be dominated by activities such as driving private cars, home central heating, and energy embodied in a wide variety of manufactured goods and the use of such goods. The welfare impacts of cutbacks of greenhouse gas emissions may thus differ greatly according to the level of personal wealth (WCED, 1987; DCCSD, 1993). Although it is a different point, it should be noted that cutbacks of greenhouse gas emissions could have significant impacts on countries where the production of carbohydrate fuels accounts for a substantial portion of their national income.

Obviously there are great variations within countries, but in aggregate the same broad issues apply concerning wealth disparities between countries. The aggregate relationship between wealth, consumption of a variety of natural resources, and emissions of various pollutants have been explored methodically by a number of authors. Using cross-sectional data, Parikh (1992) shows that consumption of a wide variety of resources--many of which involve emissions of greenhouse gases in their extraction, processing and application--is closely related to the level of wealth. Williams *et al* (1987), Drucker (1990) and others have argued that in many developed economies, a decoupling of wealth from the volume of material consumption has occurred since the 1970s and that this will accelerate, though others have disputed this (Herman *et al*, 1989); but the aggregate relationship at middle and lower income levels seems undisputed. The *World Development Report 1992* (World Bank, 1992) notes that direct emissions of many pollutants declines beyond a certain stage of economic development, but considers that this point has not been reached for most greenhouse gases, particularly CO₂ and (to a lesser extent) CH₄ from sources other than land use.

Wealth is not only one of the most important determinants of greenhouse gas emissions (at present), it also has a very important bearing upon vulnerability to climate change. Richer countries, because they are richer, will tend to find it easier to deal with the costs of coping with climate change and measures to abate climate change. Poorer countries, because agricultural production--which is particularly vulnerable to climate change--comprises a larger share of their economies than that of richer countries, will be more vulnerable to climate change. Climate change could lead to substantial migration within and among poorer countries, creating environmental refugees.

Poverty also has an important bearing upon national priorities and the timescales considered in policy. Economists have long noted that personal discount rates decline with rising income. Richer people can afford to look further ahead, have greater security, and can afford to invest more for the future (though in fact the pattern of investment as a fraction of wealth is very variable). Poor people tend to be focused more upon short-term concerns, including those of striving to ensure that they can meet basic needs. This has important implications for the potential equity impact of policies to address climate change within countries, as noted earlier in this chapter, and the same applies at the level of national economic and political systems.

Thus, in poorer countries interest rates tend to be higher, capital is scarcer, and the whole focus of policy and politics tends to be upon meeting pressing short-term needs ranging from poverty alleviation and employment generation to the management of fiscal crises, often driven partly by the needs of debt repayment. At the industrial level, the focus may for example be upon the scramble to construct infrastructure and capacity fast enough to meet rapidly rising demand, rather than the more considered examination of optimal investments over longer periods that may be possible in richer countries. Thus the context both for actual investment behaviour and broader public policy is strongly affected by national wealth in ways that are directly relevant to the climate problem (Mathur, 1991).

Some of these issues were addressed by the IPCC Special Report on Developing Countries (1990), which stated that 'the priority for the alleviation of poverty continues to be overriding concern of the developing countries; they rather conserve their financial and technical resources for tackling their immediate economic problems than make investments to avert a global problem which may manifest itself after two generations . . .'. Article 4.7 of the Framework Convention on Climate Change also recognises that "economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties" and that will influence implementation of their commitments.

III.3 Patterns of Greenhouse Gas Emissions

A second important dimension of difference is that countries vary widely in the nature and degree of their contribution to climate change. Contributions to climate change span many different gases and sources.²⁴ Although the range of sources and sinks may not in itself be regarded as an equity issue, it is clear the conclusions that may be drawn from different ways of aggregating and presenting the data can be., This section summarizes the main approaches that have been taken and the results obtained.

During the negotiations of the FCCC, many of these considerations came to be discussed in terms of whether the Convention should adopt a "comprehensive" approach and if so, whether it should focus on "gross" greenhouse gas emissions or "net" emissions derived by subtracting the removal of greenhouse gases by sinks from total emissions by sources (Bodansky, The UN Convention on Climate Change: A Commentary, Yale Journal of International Law, Summer 1993, Volume 18, 2). Adoption of the comprehensive approach means that all sources and sinks of different greenhouse gases have to be considered in formulating policy. Accordingly, global warming potentials are calculated for each gas to permit emissions of different gases to be compared according to a single metric. During negotiations many developing countries viewed the comprehensive approach as inequitable, arguing that methane emissions from subsistence agriculture should not be compared with carbon dioxide emission, because the former are "survival emissions" which cannot be controlled without irreparable social and economic damage whilst the latter are due in large part to profligate lifestyles in the North (Bodansky, p. 518). Developing countries also argued that the Convention should include a principle that all states have an equal right to ocean sinks as these are part of the global commons (Bodansky, p. 502).

This principle did not find its way into the Convention and the question of entitlements to global sinks therefore remains open. The Convention does, however, mention the comprehensive approach favorably in both the preamble and Article 3.3. Notwithstanding this mention, the final language of the Convention leaves open the possibility that policies and targets for individual gases can be adopted.

Many of the equity concerns about how sources and sinks should be dealt with, and which gases should be controlled on what timescale, continue to manifest themselves in fierce methodological disputes about the calculation, aggregation and presentation of data. This was vividly illustrated in an important debate about data relating to emissions and sinks presented initially by the World Resources Institute (see box).

In terms of controlling emissions, it is relevant to note that CO₂ is the biggest anthropogenic contributor to radiative change to date, and is projected to continue to be so. Methane is also significant, though it decays much more rapidly and emissions are much more uncertain, and in recent years the growth rate in the atmosphere has slowed dramatically. CFC emissions, almost entirely from industrialised countries, grew very rapidly until the late 1980s, but the overall impact on radiative forcing, taking into account indirect effects, is such that even the sign is not certain (IPCC, 1992). Also, since these emissions are now being rapidly phased out under the Montreal Protocol and amendments, with limited interim growth in developing countries, they are less relevant to future policy. The replacement of CFCs by HCFCs, which have a high radiative impact and are not controlled by the Montreal Protocol, however, is a matter of concern and their increased use deserves close scrutiny. Similar remarks apply to sulphur dioxide—not a greenhouse gas, but one thought to have considerable indirect impact upon radiative balance. The role of other anthropogenic gases is not big enough to affect the equity issues discussed here.

III.3.a Historical and cumulative emissions

Cumulative past emissions account for the build-up of gases in the atmosphere. Smith (1993) provides the most thorough account of how indices of past emissions can relate to current concentrations, and gives data for cumulative carbon emissions in the period 1950-86. The most extensive database of cumulative emissions are those developed by the International Institute of Applied Systems Analysis (IIASA), with estimates of fossil fuel and biotic carbon emissions back to 1800, and methane, presented to a useful but manageable degree of regional breakdown. Their results are shown in Table 1.

Considered on this basis, these results suggest that North America accounts for about a third of the contribution from fossil fuels, Europe over one quarter, and the former USSR 14 percent; the industrialised countries together account for 84 percent of the total. When estimates of biotic (mostly deforestation) emissions are included, the North American figure is reduced to about 30 percent, and the contribution from a number of developing countries becomes significant; in total the North accounts for about two thirds of the total.

The WRI data controversy and allocation of sink capacity

In 1990 the World Resources Institute (WRI, 1990) published an extensive set of data on national greenhouse gas emissions, from which they concluded that responsibility for climate change was shared widely between countries in the industrialised and developing world. Their methodology and conclusions were vigorously attacked by Agarwal and Narain (1991), who claimed that the analysis was inherently biased against poor countries; they presented an alternative approach, which led them to conclude that developing countries bore no responsibility for the problem, but were in fact contributing to cleaning up emissions from the industrialised world. The dispute attracted widespread academic, public and political attention.

There were important disagreements over the accuracy of data and the range of gases included (Ahuja, 1992; Thery, 1992), and it has now been recognised that emissions from deforestation, and probably methane, in many developing countries are much lower than in the original WRI estimates. But the heart of the dispute was over the assignment of 'natural sink capacity'—the natural processes that remove greenhouse gases.

Because of all the difficulties associated with estimating, comparing and projecting greenhouse gas removal over time, WRI took the *measured increase in concentration* of each gas—which gives a direct measure of the radiative change—and assigned this to each country *in proportion to estimated emissions in that year* (or an average of recent years).

Agarwal and Narain raised two central objections to this measure. First, that it took no account of the distribution of historical emissions, which are in fact largely responsible for current concentration levels. Second, that by distributing the *net* concentration in proportion to *gross* emissions, the natural reabsorption—the 'sink capacity'—was implicitly being allocated in proportion to emissions. This, they contended, was a grossly inequitable approach, because the sink capacity was a natural, global common resource which should be allocated equally to all people. By dividing the total annual absorption of each greenhouse gas (the difference between gross emissions and measured atmospheric increase) in proportion to national population, they showed that most developing countries' share of the global reabsorption of greenhouse gases on this basis exceeded their actual gross emissions; and hence concluded that far from bearing any responsibility for the problem, were in fact helping to clean up the excessive emissions from industrialised countries.

An important difficulty with Agarwal and Narain's approach, in turn, is that the rate at which greenhouse gases are removed from the atmosphere depends upon the concentration gradient and thus the level of gross emissions: the more that is emitted, the more is removed. Indeed the simpler physical models use a constant 'airborne fraction' and decay rate, so that the fraction of gross emissions removed in the atmosphere is a fixed percentage of gross emissions. Thus it does not follow from Agarwal and Narain's approach that concentrations would decline if all countries did emit at the per-capita rate of the poorer countries; after a few years it is likely that concentrations would still rise, but at a much slower rate. Conversely however, the 'airborne fraction' is a crude proxy for a much more complex process, and it is widely believed that it declines with increasing global emissions; thus as global emissions grow, the absolute removal increases but not in constant proportion (Ahuja, 1992).

To avoid this complication, and in keeping with much of the literature, in considering current and projected emission rates the data in this chapter are given in terms of gross emissions. Most analysis recognises that from a policy perspective it will also be necessary to consider *anthropogenic* stimulation of sinks (primarily tree planting), and probably human impacts on the ability of natural ecosystems to act as sinks (absorb greenhouse gases). For the present at least, these impacts are not thought to be major contributions to the overall flow of greenhouse gases, though the spread of land management for agriculture and other purposes, and desertification, have probably reduced the sink capacity in many diverse countries.

Table 1
Historic CO₂ and Methane Contributions by Region

	Past contribution, 1800-1988 in percentages		
	Industrial CO ₂	Total CO ₂	CO ₂ + CH ₄
OECD North Am	33.2	29.7	29.2
OECD Europe	26.1	16.6	16.4
Eastern Europe	5.5	4.8	4.7
Former USSR	14.1	12.5	12.4
Japan	3.7	2.3	2.3
Oceania	1.1	1.9	1.9
China	5.5	6.0	6.3
India	1.6	4.5	4.8
Other Asia	1.5	5.0	5.2
N. Africa & Md-East	2.2	1.7	1.8
Other Africa	1.6	5.2	5.2
Brazil	0.7	3.3	3.3
Other Lat Am.	3.2	6.5	6.5
"North" (1-6)	83.8	67.8	66.9
"South" (7-13)	16.2	32.2	33.1
World	100.00	100	100

Source: Grubler & Nakicenovic, 'International Burden Sharing in Greenhouse Gas Reduction,' Table 3.6.

Including methane makes very little difference to these results, partly because of the shorter residence time in the atmosphere. Compared to *current* populations, the ratio of cumulative emissions per capita between the "North" and "South" is more than 10 to 1.

These estimates can be subjected to the criticisms that Agarwal and Narain (1991) raised in connection with an index of current net emissions (see box). By "discounting" emissions to reflect absorption of gases, there is an implicit assignment of the earth's past "sink capacity" in proportion to emissions. Fujii (1990) and Meyer (1992) furnish calculations to show that if the total CO₂ absorption were assigned on an equal historic per capita basis, most developing countries are in fact "in credit"—their cumulative emissions are smaller than the global average per-capita absorption, and so on this basis their past contribution is not merely small but actually negative.

Some logical problems with this latter approach are noted in the box. On a more directly physical definition of "relative contribution to the build-up of greenhouse gases"²⁵ the contribution of developing countries is positive, but probably (even) less than that indicated in Table 1. On any measure, the contribution of the world's poorer regions to the total build-up

of greenhouse gases over the past century is modest, and even more so when considered in relation to population.

III.3.b Current emissions

"Responsibility" for the problem is much more sensitive to the index chosen for current emissions than it is for cumulative contributions. The most important issue is whether one focuses upon total or per-capita emission rates. Developing countries tend to focus upon the latter, as an index which highlights the extent of North-South disparities in emissions associated with individual lifestyles, and consequently as a way of emphasising what they consider profligate and unsustainable Northern lifestyles as the root of the problem. Commentators from industrialised countries more often point out that in terms of climate change it is total emissions that matter, and that per-capita indices ignore the important element of gross population itself as a causal factor.²⁶

In reality of course both aspects matter, and the illuminating way of presenting the data is in a form which displays both simultaneously. This is done in Figure 1, in which 1993 emissions of CO₂ from fossil fuels are illustrated on a graph of per-capita emissions against population: the area of each block, as the product of the two, represents total fossil CO₂ emissions from the country or region.

Figure 1 About Here

Projection against the per-capita axis illustrates the scale of these disparities, not just North-South but within groups. North America and Australia emit between 4.5 - 6 tonnes of carbon per person on average. The figure for the industrialised regions of the "Old World"—including Russia and the former Central/East Europe after the contractions of recent years—are between 2-3 tC/cap. Average per-capita emissions in many parts of East Asia and Latin America are in the range 0.5-1 tC/cap, though some of the Asian "Tiger" economies have already risen well above this. Per-capita emissions on the Indo-Pakistan subcontinent and much of Africa rarely exceeds 0.3tC/cap—a tenth or less of the per-capita emissions in the industrialised world. Others—such as the Middle-East and various island states—vary widely within this range.

Considering the population axis gives a counterpoint to this picture—many of the blocks which are much lower in Figure 1 (low per-capita emissions) are also much wider (high population). The developing economies of Asia alone account for more than half the global population. Despite their lower per-capita levels, this makes them significant contributors to the total—the area of the individual blocks shown in Figure 1. In total, in 1993 the OECD countries accounted for about 50.5 percent of global fossil carbon emissions, with about half of this being from the US; the former USSR and Eastern European countries accounted for 17 percent (with half of this being from Russia); and the developing countries contributed just under a third of gross fossil carbon emissions (with over 40 percent of this from China).

Another basis for comparing emission profiles is to consider the "productivity" of emissions--emissions per unit of economic output as conventionally defined. This tends to receive more emphasis in developed countries, that are generally more efficient, and again has its counterpart in considering total economic output, indicating what some developing countries characterise as over-consumption. Northern economists tend to put the spotlight on the lower efficiency levels in developing countries, whilst others attack the overall high level of Northern consumption as the root of the problem. Again, it is possible to demonstrate both dimensions on a single graph of emissions intensity versus GDP (Figure 2). This illustrates the somewhat lower carbon intensity of most developed economies, and the extent to which this is offset--or swamped--by higher overall consumption levels.

Figure 2 about here

Data for sources other than fossil CO₂, as noted, are much more uncertain, but in general the disparities between industrialised and developing countries are greater for CFCs, and less for all other sources, than those noted here for fossil CO₂. Most notably, almost all emissions from deforestation--thought to be in the range 15-25 percent of total CO₂ releases in the early 1990s--are from a relatively small group of developing countries, whilst anthropogenic methane emissions are probably predominantly from Central/East Europe (fossil methane) and Asia (agricultural methane) [to be checked against recent IPCC estimates]. How these emissions compare with fossil CO₂ data depends upon the data and comparison basis chosen, as discussed in the IPCC 1992 supplementary report. The statement that the industrialised and developing worlds account for about half of gross anthropogenic greenhouse gas emissions each is within the range of data and comparison uncertainties (SEI, 1991), but as noted this obscures both large disparities in average per-capita emissions, and important regional, national and sub-national variations within each group.

III.3.c Future emissions

The pattern of emissions is changing--it has indeed changed markedly in the last 5 years--and is expected to continue changing. Work on scenarios for this IPCC report has shown the very large number of emission scenarios that have now been prepared, with a variety of assumptions, timescales and degrees of regional breakdown.

From an equity perspective it is important to distinguish "business as usual" projections from assumptions about the location of abatement, and to have a sufficient regional breakdown to relate emission patterns to economic and other regional differences. The scenarios of the first IPCC Assessment Report (unlike the 1992 update) had sufficient clarity on both counts, and were criticised as embodying highly inequitable assumptions, both in the reference scenario and in the apportioning of emission reductions in abatement scenarios. Parikh (1992) noted that the reference scenario 'permitted' substantial increase in North American emissions, but considered that 'cuts for the South are already built into the reference models' compared with the rates of growth that might otherwise be expected; and she argued that 'the stabilisation scenarios stabilise the lifestyles of the rich and adversely affect the development of the poor.'

The IPCC 1992 scenarios span a very wide range, with little geographical detail, and thus do not embody a clear view of the distribution of emission trends. A more recent and much more thorough development of emission scenarios for fossil fuels is that by the World Energy Council (WEC, 1993), which developed regional scenarios both from a global perspective and with regional teams. Interestingly, their reference scenario was also criticised by participants from the developing world and former USSR for being too optimistic about the prospects for improved energy efficiency in these regions; taking account of these concerns led to a variant of the reference scenario with much higher emissions particularly in South Asia, Central/East Europe, and Africa.

Whichever variant of future scenarios is considered--and especially for the higher growth cases favoured by many in the developing world--the vast majority contain a clear message. The ambiguities about whether the developing world holds significant responsibility for contributing to climate change will not persist for long. Even in relatively restrained scenarios of emissions growth from the developing world, such as the original WEC reference case, fossil CO₂ emissions alone from these countries those of the OECD by 2020. And in many scenarios, before the year 2050, fossil CO₂ emissions from the current developing nations exceed the global total emissions today--despite still being considerably lower in per-capita terms (both factors of course partly reflecting population growth). Furthermore, in terms of the distribution of abatement efforts, there are significant spill-over effects, both positive and negative.²⁷ Bradley *et al* (1994) note on the basis of a range of abatement scenarios, 'anthropogenic climate change cannot be controlled by the OECD nations alone'.

Emissions from deforestation do not--probably cannot--keep pace with projections of fossil fuel emissions; the projections reviewed in the IPCC 1992 assessment almost all stay below 2GtC/year, and decline after 2030, compared with global projections of global fossil fuel emissions rising above 10GtC/yr by this date in many 'reference' scenarios. Methane projections are highly uncertain but also suggest slower growth. Clearly, neither is likely to alter substantially the overall trend in the distribution of emission sources. Whatever the past and current responsibilities and priorities, it is not possible for the rich countries to control climate change through the next century by their own actions alone, however drastic. It is this fact which necessitates global participation in controlling climate change, and hence, the question of how equitably to distribute the burden of climate change on a global basis.

III.4 Vulnerability to climate change

Another aspect--distinct but again partly correlated with both wealth and institutional capabilities--is the likely differential impact of climate change. The work in both the IPCC Working Group II, and the chapter in this report on assessing and valuing the impact of climate change, note that impacts may vary considerably between countries. Small island states and countries with low-lying coastal areas are an obviously vulnerable group, not only because of their greater susceptibility to sea-level rise, but also their heavy dependence upon natural resources that may be affected by climate change, and traded commodities that may be affected by abatement (Saha, 1994). In addition to these adverse economic impacts, these countries may face

destruction or uninhabitability of all or part of their territories. This in turn may have profound consequences for their human communities as well as entire ecosystems. This is an important equity issue not only because the impacts differ, but also because those most vulnerable to climate change are to a large extent those contributing very little to its causes. For small islands, but also for many other developing countries, adaptation to climate change may be a more important, and more urgent, task than planning and undertaking national mitigation policies.

Possible implications of this for international responses aimed at coping with climate change and minimising the impacts are considered in the next section. Here it is important to note that assessing the consequences of the vulnerability of countries to climate change requires valuing the damage that may arise from climate change. Any attempted valuation of damage unavoidably requires estimating and aggregating impacts on different people in different countries across different timescales. But as discussed in the introduction this chapter, there is no single "right" way to do this; it can only be done by making ethical judgements about what to measure, and how to measure and compare the welfare of different people in different countries across time. Considering only impacts on Gross World Product is a poor enough indicator for the reason outlined in the introduction (and discussed in the chapter on evaluating impacts below) that this indicator makes no pretence to be a real measure of welfare. But if it is predominantly poorer people who are affected, it is even worse as an indicator, because poor people add very little to aggregate wealth--and impacts on them are similarly discounted (Ayres and Walter, 1991).

Attempts to allow for 'non-market' impacts, such as those on human health and environment, require assumptions to be made about how to value and aggregate such impacts on different people in different countries. Scaling impact costs according to relative GDP implies valuation of human impacts based upon average earning power. Implicit valuation also differs greatly between countries, partly because it is constrained by aggregate wealth, and the blunt fact is that societies clearly do not value people in other countries equally. One of the most significant aspects of climate change is that activities of people in one country can have destructive consequences for people in other countries. Any aggregation that evaluates and aggregates impacts in relation to national wealth (such as impacts on GWP, plus non-market impacts related to national GNPs) in effect embodies an assumption that the human impact is less significant if it is poor people, or people in poorer countries, that suffer.

If poorer countries are more vulnerable and are likely to suffer more, the dominant impacts are likely to be precisely in those regions. The question of how they are valued thus becomes central to any evaluation, and cannot be passed off simply as inevitable economic logic (Grubb, 1993). Hence, it needs to be recognised that attempts to quantify the costs associated with climate change involve inherently difficult and contentious value judgements, concerning which different assumptions may greatly alter the conclusions.

III.5. Social Considerations

Methodological disputes about the best way to measure vulnerability may also disguise the fact that it may be impossible or inappropriate to attempt an economic evaluation of some of

the impacts of climate change. For some small islands and countries with low-lying coastal areas, climate change may lead to the destruction of all or part of their territories. This loss may have profound social impacts for their communities including, inter alia, destruction of indigenous cultures and whole communities, with the loss of their attendant heritage and spiritual, cultural and social values. This loss in human diversity does not appear to command as much attention in literature as the loss of biological diversity which is valued in itself as well as its scientific and economic values.

It is also important to bear in mind the human dimension of physical impacts such as storm surges, hurricanes, sea level rise and changing climate patterns. The burden of "adapting" to these events will fall more heavily on the parts of the communities that may already be disadvantaged and unable to adapt without further hardship. The more extreme of these events may result in the creation of environmental "refugees" and changed patterns of migration as human communities adapt to climate change. Climate change thus could well exacerbate problems of both domestic and international refugees.

Methodological debates about how best to value damage may overlook the fact that no amount of monetary compensation may be sufficient for communities that have had no choice but to bear the burden of adaptation. This has important equity implications for deciding whether mitigation or prevention of climate change is preferable to adaptation. The language of the Framework Convention on Climate Change does not give mitigation absolute priority as it accepts that some countries and communities will have to adapt to climate change. However, the acceptance that developed country parties must assist developing country parties that are particularly vulnerable in meeting the costs of adaptation indicates that negotiators agreed it would be inequitable for members of the international community that were vulnerable to climate change to bear the costs of that vulnerability alone.

Adapting to climate change will also present a social and institutional challenge for many countries. Countries are not equal in their capabilities to deal with such challenges and it is important to note that countries differ in these respects. Some are strong nation-states, with a large degree of societal consensus and strong institutions that can formulate and implement policy effectively, and which can act to protect weak and vulnerable groups--for example, against the effects of climate change. Others may be driven by internal differences, and have fragile governing institutions that may be unable, or unwilling, to formulate and implement effective policy or to protect the most vulnerable groups--institutional structures which indeed may themselves be vulnerable to the stresses that climate change may bring.

Relatively little literature exists examining public perceptions and social responses to climate change, in particular, how different social groups view global environmental problems. Such research would appear necessary as a first step to increasing public participation in ameliorating these problems (see "Human Dimensions of Global Warming: They Should Not be Ignored", Ragner E. Lofstedt, Centre for Environmental Strategy, University of Surrey).

At a lesser but still important level, some countries may have strong traditions of independent research and analysis to help them understand complex issues, and have the

resources to back such work and bring it to bear on international decisions; others may have neither.

To a degree--but not entirely--these differences correlate with wealth. The IPCC Special Committee on Developing Countries for the 1990 Assessment also highlighted the importance of such differences, which affect a whole range of aspects of climate change, including the ability of countries to participate effectively in international analysis and negotiations, and the ability to implement efficient response strategies both for mitigation and adaptation.

Possible implications of this for responses aimed at coping with climate change and minimising the impacts are considered in the next section. Here it is important to note that this issue can also profoundly affect attempts to value the damage that may arise from climate change. This unavoidably requires estimating and aggregating impacts on different people in different countries. But as discussed in the introduction to this chapter, there is no single 'right' way to do this; it can only be done by making ethical judgements about how to measure and compare the welfare of different people in different countries. Considering only impacts on Gross World Product is a poor enough indicator for the reason outlined in the introduction (and discussed in the chapter on evaluating impacts below) that this indicator makes no pretence to be a real measure of welfare. But if it is predominantly poorer people who are affected, it is even worse as an indicator, because poor people add very little to aggregate wealth--and impacts on them are similarly discounted (Ayres and Walter, 1991).

Attempts to allow for 'non-market' impacts, such as those on human health and environment, require assumptions to be made about how to value and aggregate such impacts on different people in different countries. Scaling impact costs according to relative GDP implies valuation of human impacts based upon average earning power. In welfare economics this approach is contentious; for example many societies, directly or by implication, clearly value life much more than a "foregone earnings" measure implies (Frankhauser, 1993; and see Evaluation chapter in this report).

Implicit valuation also differs greatly between countries, partly because it is constrained by aggregate wealth, and the blunt fact is that societies clearly do not value people in other countries equally. But climate change concerns impacts caused by the activities of other people--predominantly more wealthy people--mostly in other countries. Any aggregation that evaluates and aggregates impacts in relation to national wealth (such as impacts on GWP, plus non-market impacts related to national GNPs) in effect embodies an assumption that the human impact is less significant if it is poor people, or people in poorer countries, that suffer.

This is a highly contentious ethical assumption. But if it is correct that poorer countries are more vulnerable and are likely to suffer more, the dominant impacts are likely to be precisely in those regions. The question of how they are valued thus becomes central to any evaluation, and cannot be passed off simply as inevitable economic logic (Grubb, 1993). Hence, it needs to be recognised that attempts to quantify the costs associated with climate change involve inherently difficult and contentious value judgements, concerning which different assumptions may greatly alter the conclusions.

III.6 Differing resource endowments

Finally, countries differ widely in their endowment of resources that may be affected by efforts to *mitigate* climate change, and in their current reliance upon production or conversion of these resources. Coal resources and production are relatively widespread globally, though with major variations within regions. Remaining oil reserves are heavily concentrated in the Middle East, Central America and former Soviet Union; for some Middle Eastern countries especially, oil is their only significant export and source of foreign exchange. Proved gas reserves are also quite concentrated in the Middle East and Russia (though their value would probably be enhanced by mitigation efforts). Forests, and timber exports, are likewise concentrated, to a limited number of developing countries. The value of such resources can be affected by action to limit climate change, though the actual equity implications may be complex as discussed later in this chapter.

III.7 Conclusions

This section has illustrated several ways in which countries differ that are relevant to formulating climate change responses. A number of these group along a "North-South" axis: the implications for developing countries are different because they are generally poorer, have contributed much less to past emissions and still emit much less per-capita, and they may have shorter policy time-horizons, weaker institutions, and be more vulnerable to climate change. Yet in other respects the divisions are much more complex. There are substantial variations within the "north" and within the "south" in terms of absolute and per-capita emissions, the likely impacts of climate change, institutional strengths and preferences, and endowment of natural resources that may be affected by mitigation. Similarly, in the next century some developing countries will continue to make marginal contributions to the problem whilst emissions from others may well start to dominate it. A rigid "north-south" delineation of equity issues in the debate is thus inappropriate and may indeed be highly damaging in the long run, though it inevitably permeates many components of the debate at present.

The rest of this chapter concerns the implications of the various differences for what might constitute equitable responses. In structuring it, we draw upon the observation by Shue (1992) that the equity issues in responding to climate change comprise at least four distinct questions:

- distribution of the costs of coping with climate change;
- distribution of future emissions;
- distribution of the costs of measures to limit emissions; and
- the background allocation of resources and capabilities and consequent basis for fair bargaining and fair processes

1234 All these questions are interrelated. For example, a "fair" distribution of future
 1235 emissions may depend somewhat upon how much countries help others with the costs of
 1236 coping; a fair distribution of abatement costs depends upon various background circumstances;
 1237 and debates about allocating the "burden of abatement" in general, and joint implementation
 1238 and tradable emission quotas in particular, highlight a particularly strong link between ii) and
 1239 iii). Few authors in fact have distinguished these different components; but they are distinct
 1240 and it is useful to address the equity issues each raises in turn, even if two or more of them
 1241 may in practice be tied or even addressed through the same instruments.

1242
 1243 This next section considers the question of the costs and risks of coping. The following
 1244 then considers the common issues surrounding distributing emissions and the costs of
 1245 abatement, before summarising specific proposals concerning each in turn. The final sections
 1246 then examine internal equity, and procedural equity issues.

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IV Distributing the costs of coping: impacts, risks and international insurance

1251 The previous section has noted the fact, analysed more fully elsewhere in the IPCC SAR
 1252 report, that some countries are likely to be much more affected by climate change than others.
 1253 To an important degree, poor countries may be much more vulnerable than richer countries.
 1254 But all projections of impacts are fraught with uncertainty--in some scenarios parts of the
 1255 developed world could also be badly affected for example--and thus the issue is also about
 1256 sharing and minimising risks. This section reviews these issues.

1257 *IV.1 Nature of impacts and uncertainties*

1258
 1259 Predictions of climate change remain highly uncertain. The uncertainty about the future
 1260 average temperature is high enough, but it is local effects that really matter, and predictions of
 1261 regional changes are even more uncertain and can vary substantially between different climate
 1262 models. It may even be that in some areas the temperature will go down, but we cannot predict
 1263 with any confidence where, because it depends upon atmospheric and ocean current patterns
 1264 that are not well understood. The impact from climate change will also depend heavily upon
 1265 changes in precipitation and winds; the climate models predict in general that precipitation will
 1266 go down in the interior of continents while it will increase elsewhere but again with wide
 1267 uncertainties. Sea level rise is predicted, with widely differing impacts, but again the rate is
 1268 uncertain and could vary between regions because of shifting pressure patterns and other
 1269 factors. Climate change could increase the frequency and/or severity of droughts, heavy storms
 1270 and hurricanes, and in general the frequency of violent fluctuations in the weather. These
 1271 fluctuations will not in general be predictable (except in a probabilistic sense), and will
 1272 therefore add to the uncertainty.

1273 It is not likely that such uncertainties can be resolved quickly, and it may always remain
 1274 impossible to make reliable local predictions or to associate particular local impacts with
 1275 human-induced climate change, because to an extent the climate is inherently chaotic;
 1276 variations may be extremely sensitive to the initial situation (for a popular discussion of
 1277 dynamical systems and their inherent unpredictability see Gleick (1987)).

1278 Thus, in discussing climate impacts it is better to refer to 'expectations' of costs and
 1279 benefits, in the mathematical sense of an average of possible outcomes; and to recognise
 1280 simultaneously the importance of uncertainties. This implies there is another cost item--the
 1281 cost of bearing risk. Thus, we can categorise the distributive issues arising from climate
 1282 change impacts into four groups:

- aggregate welfare impacts over time (intertemporal distribution of expected global utility)
- welfare impacts between countries (international distribution of expected utility)
- welfare impacts within countries (interpersonal distribution of expected utility within countries)
- the distribution of the cost of risk bearing associated with each of the above.

The question of aggregate intertemporal distribution is the subject of the next chapter. Concerning impacts within countries, over and above implementing policies promoting redistribution, governments generally accept responsibility for trying to manage, respond to and mitigate the worst impacts of extreme events—for example, with government relief programmes for victims of major storms. Big disasters in the developing world will also often in addition mobilise international relief efforts, though as noted by Rahman (1993) in the context of Bangladeshi cyclone disasters, these tend to be quite short-lived; after the initial effort, the local people, with some assistance from the government, tend to be left to rebuild their lives.

The new aspects introduced by human-induced climate change thus concern the broader impacts upon international welfare distribution, and the cost of associated risks. We consider each in turn.

IV.2 *Paying for the costs of coping*

If there are no international transfers or other assistance connected directly with the measures to cope with actual or potential impacts of climate change, each nation in effect is expected to cope using its own resources. The available literature appears to be unanimous in considering this inequitable, for two main reasons.

The first arises directly from the observation above that poor countries are likely to be much more vulnerable to climate change. Climatic change is thus likely to exacerbate existing inequalities. Most ethical systems would anyway expect richer parties to contribute more to addressing a common problem; the rationale is much stronger still when the cause is shared but the impacts are disproportionately large on the least well off parties.

The second factor, which applies irrespective of this inequitable distribution of impacts (but is much reinforced by it) is the direct causal link: the fact that the actions of some people (emitting greenhouse gases) may directly harm others. There are few if any ethical systems in which it is acceptable for one individual knowingly to inflict potentially serious harm upon

another and not accept any responsibility in helping or compensating the victim, or to pay in some other way. An analogous principle in international law provides that a state may exploit its resources but has the responsibility to ensure that activities in its jurisdiction do not cause harm to the environment of other states or to areas beyond its national jurisdiction. This principle is generally accepted as a rule of customary international law. Its application to the climate change context is problematic, however, as it is extremely difficult for one state to prove before an international court or tribunal a direct causal link between another states' emissions and its own environmental damage. Although upon signature of the Framework Convention on Climate Change a number of small island countries indicated that they may rely on traditional rules of international law to address damage to their environment from climate change, it is widely recognized that it would be factually and legally difficult to use these rules successfully.

This points to the need to develop general rules of international law regarding liability and compensation which was formally accepted at the intergovernmental level in Principle 21 of the Stockholm Declaration, and re-emphasized in Principle 13 of the Rio Declaration which provides:

“... States shall also cooperate in an expeditious and more determined manner to develop further international law regarding liability and compensation for adverse effects of environmental damage caused by activities within their jurisdiction or control to areas beyond their jurisdiction.”

In the absence of new rules of liability the traditional “fault-based” rules of responsibility of international law could provide a basis for vulnerable, generally poorer, states adversely affected by climate change to receive compensation from richer states whose past and present emissions of greenhouse gases had caused environmental harm. The issue of historical emissions could be of direct relevance here as climate impacts are a function of atmospheric concentrations which depend strongly upon cumulative emissions. Whilst the Convention's preamble recognizes that the largest share of historical and current global emissions of greenhouse gases originated in developed countries, and that per capita emissions in developing countries are relatively low and will need to grow to meet their social and development needs, its legal ramifications remain unclear.

IV.3 *Sharing risks*

The question of who should pay is not solely about equity; it also concerns more classical economic issues about sharing risks. Chichilnisky and Heal (1993) (drawing on Cass, Chichilnisky and Wu (1991)) note that the risks involved have four important characteristics--they are:

- I. poorly understood - we cannot assign clear probabilities to different impacts;
- II. endogenous - they are created or affected by our own actions;
- III. collective - given climate impacts may affect large numbers of people and so risks are not statistically independent and hence cannot be greatly reduced by "pooling";
- IV. irreversible - impacts cannot in general be reversed and indeed may be committed long in advance.

This results in a complex combination of issues of equity and decision-making under uncertainty. Decision-making when the probabilities of different outcomes are known or reasonably estimated ("risk") is a field of extensive economic study, for which techniques of expected utility can be applied (Ramsay, 1931; von Neuman and Morgenstern, 1944). Rational decision-making when the probabilities of different outcomes are not known is more difficult but is still a subject of considerable analysis, for example using notions of subjective probability distribution (Savage 1951, 1954). Luce and Raiffa (1964) give a discussion which is still very much up to date, and the issues are discussed further in the decision-making chapter of this report.

One criteria for decision-making under extreme uncertainty is the 'maxi-min' criteria, which is to select the strategy that minimizes the worst outcome. Its basis is similar to that of Rawl's criteria for equity. It recommends avoiding those strategies that could generate the worst outcomes. The maxi-min principle bears some resemblance to the precautionary principle expressly included in the Convention in Article 3.3 which provides that:

Parties should take precautionary measures to anticipate, prevent, or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.

A philosophic and economic examination of risk-bearing, including the max-min principle, may provide insights relevant to the application of the precautionary principle. The maxi-min criteria is however, rather conservative because it takes into account only the worst outcome and not the nature of the other outcomes from a strategy. In practice, climate change is not a situation of total ignorance--we have some idea of plausible outcomes and their relative probability. This increases the appropriateness of approaches based upon subjective probabilities, combined with an appropriate measure of risk aversion to reflect the cost of bearing risk (see box).

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The Cost of Bearing Risk:

In order to understand the meaning of the cost of risk bearing, consider a very simple case with two outcomes, A and B. In A the monetary gain is M_A and in B the gain is M_B . Let the probabilities for the two outcomes be p and $1-p$. The expected gain is then $pM_A + (1-p)M_B$ which we will denote by M . Is the decision-maker indifferent between the uncertain prospect $(pM_A, (1-p)M_B)$ and the certain gain of M ? If yes, he or she is said to be risk-neutral and if their utility function is u , it implies that:

$$pu(M_A) + (1-p)u(M_B) = u(M) = u(pM_A + (1-p)M_B),$$

i.e., the utility function is linear. However, most evidence indicate that the utility function is concave, i.e., it increases with the gain but the rate of increase goes down as the gain goes up. This has the important implication that:

$$pu(M_A) + (1-p)u(M_B) < u(pM_A + (1-p)M_B).$$

The individual would prefer the certain outcome M to the uncertain prospect, although they have both the same expected value. This also means that the individual would be willing to sacrifice an amount in order to ensure a certain outcome. This willingness to pay is defined as the c of risk-bearing. Let C be this cost. Then it is defined from:

$$pu(M_A) + pu(M_B) = u(pM_A + (1-p)M_B - C)$$

C is the maximum insurance premium the decision-maker would be willing to pay in order to eliminate the uncertainty. If the uncertainty is not eliminated, then it is the cost he or she has to bear for that uncertainty.

These simple ideas have some powerful implications on equity issues in connection with global warming. The classical approach to reducing the costs of risk is with insurance. But markets do not exist in which individuals or countries could insure themselves against impacts due to changes in climate or due to changes in abatement policies; Wilford (1993), Chichilnisky and Heal (1993) and others note several reasons why commercial insurance markets cannot adequately cover against such risks;²⁸ to the limited extent they can the insurance premiums would presumably fall primarily upon the potential victims and thus represent an inequitable burden. This means that people and organizations have to bear an unnecessary burden corresponding to the cost of risk-bearing. Establishing global insurance in an appropriate form could increase both efficiency and equity by reducing exposure to risk.

Climate risk is an equity issue for several reasons. There are good reasons to believe that the distribution of the cost of risk-bearing is very uneven. First of all, industrialized countries have in general better insurance markets. This means that individuals in those countries can reduce their cost of risk-bearing substantially (but not completely, partly because global warming is a collective risk and partly because the incompleteness of markets). These possibilities are not open to most individuals in developing countries, and they have therefore to bear a higher cost of risk-bearing. Secondly, the cost of risk-bearing may be much higher in some developing countries than in industrialized countries because of the nature of the impacts. For example, a range from 20 cm to 60 cm may imply a quite low cost of risk-bearing in a country like USA and the expected damage would be a good proxy for the total cost of sea level rise. For a country like Bangladesh, the difference between 20 and 60 cm may mean a substantial difference in utility, which is not accounted for in the expected damage. Thus the cost of risk-bearing in Bangladesh is much higher than in the US. The same holds true for countries that may be threatened by increase in both the frequency and the severity of droughts. The variation in utility will probably be much greater than the variation in actual damages among different outcomes and therefore, the cost of risk-bearing will be high. In the absence of empirical studies on the cost of risk-bearing the values involved are highly uncertain, but the nature of the conclusions seem reasonable.

The problem of risk becomes more severe when changes in the environment are irreversible, because irreversible change means losing future options. This was studied by both Arrow and Fisher (1974) and Henry (1974) and they showed that the combination of uncertainty and irreversibility implied that the expected net benefit is not the correct decision criteria; irreversibility should amplify aversion to risk.²⁹

IV.4 Policy implications

Most of the discussion on the economic and equity aspects of climate change impacts have focused on the 'expected' changes over time and between and within countries. But uncertainties combined with irreversibilities--both in abatement and in impacts from climate change--makes the issue of risk-bearing also of great importance. Analysis is technically difficult but not impossible, and more study is needed. For example, the combination of the idea of basic needs and risk-bearing could have far-reaching implications. If we accept that

individuals have the right to some basic goods--food, shelter, access to environmental resources--and if emitting greenhouse gases threatens the availability of these basic goods, then those who do so should be prepared to protect potential victims against losing these rights to basic goods.

The Framework Convention on Climate Change mentions the concept of insurance in Article 4.8 which provides that

"Parties shall give full consideration to actions relating to what actions are necessary under the Convention, including actions related to funding, insurance and technology transfer to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures."

In addition, Article 4.4 provides that the developed country Parties must "... assist developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting the cost of adaptation to those adverse effects."

This is a specific example, but at least two general conclusions can be drawn from the above discussion:

1. It is necessary to include the cost of risk-bearing in any equity discussion related to global warming. In particular, estimates of the costs of impacts should also include this cost component in addition to expected cost.
2. Policy should seek to establish appropriate global insurance against impacts from climate change.

The appropriate form of insurance is not however a simple matter. The characteristics of climate change discussed above lead to particular requirements for approaches to insurance, some economic principles of which are summarised in the box.

Also relevant is that fact that there are three broad kinds of costs that may be incurred in coping with climate change:³⁰

- A. preparation (or protection) to minimise the potential impacts of climate change, for example through the construction of sea defences, improved water storage or water transfer capabilities, or changing the kind or diversity of crops;
- B. costs arising directly as a result of changes in the resource base (e.g. loss of land to the sea, other loss of agricultural land), and the social costs that may follow from this (Suleman, 1994);
- C. costs caused directly by extreme events, such as freak storms and droughts.

Insurance against climate risks: economic principles

The characteristics of the risks associated with climate change noted in the text create particular requirements for approaches to insurance. Simply on grounds of risk sharing (as distinct from equity), Chichilnisky and Heal (1993) argue that two classes of insurance contract need to be considered. One is in the nature of a mutual insurance contract, which is an agreement between parties subject to similar risks that 'those which are harmed will be compensated by others'; there are many precedents, for example in agricultural co-operatives. In the context of climate change the parallel would be a binding agreement in which countries that are hurt by climate more than the average (or expected) would be helped by those affected less.

The second type of 'insurance contract' is required because the overall nature of the risks, as well as its specific distribution, are uncertain. The formal treatment of an appropriate insurance structure (Arrow, 1953) is complex: it requires defining "securities" for each possible outcome, which pay out only if that outcome is realised. In the climate change case the analogy would be that each country would be required to make commitments to compensate as insurance against a particular climate "outcome". To efficiently distribute the risks, however, countries would then be allowed to trade these "securities".

This (in combination with mutual insurance contracts) would not only allow a fairer distribution of the risks, but also allows for differing beliefs about the overall risks. For example, if a country genuinely believes that climate change is unlikely to have serious global impacts, it will be more prepared to see those "securities" that pay out under these conditions. These issues are discussed in detail in Heal (1993), and a formal two-country treatment is summarised in Chichilnisky and Heal (1993), who note that creating such securities who help to provide an objective test of the honesty of national positions on the risks of climate change: if a country were to argue that climate change does not involve substantial risks as part of a negotiating ploy to avoid onerous abatement commitments, for consistency it should be prepared to see associated high-pay off securities; and "there would be a cash cost to convincing and consistent misrepresentation of true beliefs. These cash costs could offset some of the incentive to free ride on other countries' efforts to reduce greenhouse emissions."

Whilst these analyses are primarily concerned with efficient risk-bearing, they have equity implications in terms of both outcome and process, and could ease some of the dilemmas. The feasibility, credibility and equity of such securities (would and should countries that "gambled wrong" be made or allowed to suffer accordingly?) remains to be considered and could be an important research topic.

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Although the underlying equity issue of who should pay is similar in each case, some of the practical issues differ. Even if there is agreement on the underlying equity principles, major practical differences and disputes may arise because of all the uncertainties surrounding climate change. General protection measures (i) have multiple benefits; views will differ on the extent to which they should be funded primarily on the basis of concerns about climate change. It is likely that victims of both underlying climatic changes (ii) and extreme events (iii) will attribute their suffering to human-induced climate change more readily than those responsible for the emissions. Insofar as international help is based on the second 'fault-based' rationale, this raises important issues about fair processes for deciding about the probability of events being tied to human-induced climate change, which none of the literature addresses explicitly.

The different nature of these costs has also led to different proposals about how to tackle them. Notably, there have been suggestions (for example in the Toronto Conference, 1988, and Beijing Declaration, 1992) for a "climate fund" to help developing countries pay for protection measures of type (i); international funding of such measures can be considered both as a matter of equity and as a way of reducing overall risks.

Also, the Alliance of Small Island States (AOSIS) have proposed creating an insurance pool to provide some cover against the impacts of sea-level rise and associated salt intrusion and storm surge damage. This was elaborated as a proposed Annex to the draft Climate Convention but removed at a late stage under pressure of the Rio deadline, and is discussed by Wilford (1993). AOSIS proposed that an insurance pool be created with international funding from governments. Two precedents are noted:

- The 1971 International Convention on the Establishment of an International Fund for the Compensation for Oil Pollution Damage, which is funded by agreed levies on oil importers; and
- The 1963 Brussels Supplementary Convention (an OECD agreement, amended by 1964 protocol) to the 1960 Paris Convention on Third Party Liability in the field of Nuclear Energy. This is funded half on the basis of GNP, and half on the basis of nuclear capacity.

The draft Insurance Annex to the Framework Convention on Climate Change proposed, by analogy with the nuclear precedent, funding through a combination of GNP and CO₂ emissions, the latter component suggested both on grounds of responsibility and to give an incentive to limit emissions.

The main criterion for entitlement to claim put forward in the draft annex was proved loss attributable to sea level rise, including storm surges. There is no reason why such an insurance pool should not, in principle, be available for countries other than small islands and for damage other than sea level rise. It could appear more equitable to extend the scope of

1542 such a fund to insurance against all kinds of climate impacts though determining cause and
 1543 effect may be more difficult in cases other than sea-level rise. The literature does not appear
 1544 to explore this issue, nor does the question of compensation or other support for other kinds of
 1545 climate coping appear to have been explored more fully, though some elements are implicit in
 1546 the more general economic treatment of insurance (see box above).
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1548 **V Distributing future emissions and abatement costs**

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1550 **V.1 Introduction**

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1552 Issues of how future emissions (or abatement efforts) should be allocated, and who
 1553 should pay for abatement, form some of the most contentious equity issues in climate policy.
 1554 As noted above, the two questions are closely intertwined; in the absence of separate
 1555 international transfers associated with abatement, the initial distribution of emission constraints
 1556 will largely determine the distribution of costs. Much of the literature has focused upon the
 1557 question of future emissions allocation, but some has addressed more directly the distribution
 1558 of costs. This section considers first issues which are common to both topics, and then
 1559 considers in turn some of the specific proposals for fair allocation of emissions and abatement
 1560 costs.

1561

1562 The applied research literature on these questions--relating specifically to climate
 1563 change policy--is limited compared to that on climate science, impacts or the economics of
 1564 responses. There are of course many short articles and statements of positions made in
 1565 newspapers, newsletters, 'non-papers' at negotiating sessions, etc.; and also some important
 1566 official declarations developed through extensive discussions to reflect consensus positions
 1567 among groups of countries (e.g. the *Beijing Declaration*, and various regional statements).
 1568 Also, the UNCED agreements themselves contain innumerable references related to equity.
 1569 Most of this is cast in North-South terms, with important additions concerning the interests of
 1570 particular groups.

1571

1572 This section attempts to reflect this material, whilst recognising the impossibility of
 1573 ensuring comprehensive coverage, and drawing heavily upon the limited deeper analysis of
 1574 international equity issues in the more conventional academic literature of books, substantive
 1575 reports and articles in peer-reviewed journals. Interestingly, of those that have contributed
 1576 such analysis, few are professionally employed as academics in the discipline which might
 1577 seem to be of greatest direct relevance--moral philosophy.

1578

1579 **V.2 Principles for shorter-term action**

1580

1581 In approaching the topic it is useful to distinguish short-term from long-term allocation
 1582 issues. In the long term, decisions will have to be taken--by design or default--about the
 1583 overall allocation of greenhouse gas emissions. The appropriate allocation depends upon the
 1584 conception of equity, and different ethical approaches may have very different implications.
 1585 But in the short term, the position is simpler. All ethical systems, and all the applied literature,
 1586 appears to point in the same direction (Shue, 1991):

1587

1588

"Even in an emergency one pawns the jewellery before selling the blankets .. whatever justice may positively require, it does not permit that poor nations told to sell their blankets [compromise their development strategies] in order that the rich nations keep their jewellery [continue their unsustainable lifestyles]."

The Framework Convention on Climate Change certainly requires that developed country Parties take the lead in combating climate change and its adverse effects. It also recognizes that the extent of developing country Parties' implementation of their commitments under the Convention depends on the effective implementation of developed country Party commitments to transfer financial and technological resources and must fully take into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country Parties. These provisions flow from the Convention's principle of common but differentiated responsibilities and Parties' respective capabilities, rather than being predicated on rich countries' unsustainable lifestyles.

The observations about what is not fair in initial distribution of emissions obligations extends to other measures of abatement effort. Notably, some earlier and overly simplified economic studies assumed that a uniform carbon tax, as an indicator of abatement effort, would distribute the "burden" equally, fairly, and efficiently. None of these three suppositions have stood up to closer scrutiny in the literature:

- a uniform carbon tax would not impose equal burdens upon different countries because of differences in existing tax structures (Shah and Larsen 1990; OECD 1992; etc.), resource endowments (Whalley and Wigle 1989; others?); and stages of development;
- even in a scheme involving "equal burdens," most observers argue that this would not be fair because of the many differences outlined in the previous section, notably differences in historical and current emissions and current wealth and consequent priorities;
- a uniform tax would also be Pareto-inefficient in the absence of optimal international lump-sum transfers, because of the differing marginal utilities between countries at different stages of development (Chichilnisky 1993a).

The literature thus demonstrates a degree of consensus about relative responsibilities and equitable directions of response in the short term, and some elements of what would not be equitable in longer term allocations. Beyond this, and in the attempt to develop more precise allocation principles, there is a far wider range of perspectives, which derive from a range of ethical approaches. We consider first some of these underlying ethical assumptions, and then consider more specific proposals for allocation of future emission entitlements and abatement costs in turn.

V.3 Longer-term allocation: underlying principles

General ethical principles underlying discussions about fair allocation fall into several categories. Several authors have sought to classify and in some cases critique equity principles applied to this question. Those attempting a fairly broad coverage include d'Arge (1989), Rose (1990), Young (1990), Grubb et al (1992), Ghosh (1993) and Bhaskar (1993). Underlying a number of these are various conceptions of utilitarianism—the "greatest good for the greatest number". As noted in the introduction this in principle underpins the quest of modern welfare economics to maximise the sum of individual utilities, but there is no consensus about how to compare and maximise individual or national utilities at the international level; some of the principles sketched here are in part an attempt to formulate more specific interpretations of utilitarianism, as well as to apply alternative or complementary ethical frameworks.

Egalitarianism

This reflects the underlying Parity principle that each human being should have equal rights, in this case with respect to access to common global resources. It underlies several specific proposals considered in the next section.

Basic needs and Rawlsian criteria

A basic needs approach in the present context involves allowing countries the right to emit the minimum levels of greenhouse gases needed to meet the basic needs of their citizens, defined as the minimum consumption levels needed to support full participation in society, and then forcing countries to buy (or pay taxes on) the rights to emission levels above these. It would perhaps be close to the allocation of emission permits according to population, although basic needs could vary from country to country depending on climate and other matters. Chichilnisky introduced, formalized and developed empirically the idea of development aimed at satisfaction of basic needs while creating a society intrinsically compatible with the environment.

This can be related to a Rawlsian philosophy. At an absolute minimum it suggests that developing countries be left at least as well-off under an emissions control regime as they would be in its absence; a stronger interpretation is that the regime should be used specifically to improve their position.³¹

The only target in the Convention requiring developed countries to aim to return carbon dioxide emissions to 1990 levels by the end of the decade applies a uniform target approach based on historical or current emissions (often referred to as the "grandfathered emissions" approach) (Bodansky, 1993). Developed country parties with economies in transition are allowed "a certain degree of flexibility" with implementation of this obligation. Developing countries are not required to limit their current emissions and the Convention's preamble recognizes that developing countries' emissions will grow to meet their social and economic development needs. These provisions could implicitly support some kind of concept of basic needs emissions entitlements varied according to national circumstances. However, it is

important to bear in mind that the Convention's negotiators could not agree on the bases of present and future entitlements to emissions (Bodansky). The inclusion of the stabilization target does not preclude the relevance of the basic needs approach to future discussions about emissions entitlements.

Proportionality and polluter pays principle

This reflects the ancient Aristotelian principle that people should receive in proportion to what they put in, and pay in proportion to their contribution to damage caused. This has a clear potential relationship with the polluter pays principle, which is formulated as a principle of economic efficiency that in the context of international pollution can be interpreted in a number of ways as discussed below.

Historical responsibilities

Many authors consider that allocation should be strongly influenced by the patterns of past emissions. This has been a particularly persistent theme in North-South debates. Hyder (1992) draws together several of the underlying rationales in expressing the perception of many developing countries:

"It is difficult for most of the developing countries to accept the proposition that they should enter into commitments which would adversely bind them, either now or later on, for the sake of a problem caused by the developed countries--who neither wish to equitably share the remaining emission reserves in the atmosphere, nor to share (even in a small way) the benefits and resources that they have built up by plundering the world's greenhouse gas reservoir capacity."

This illustrates that several issues are involved in the general assertions about historical responsibility: ownership of the emissions potentially responsible for transboundary impacts; prior use of a finite stock (the atmosphere); and current monopolisation of the benefits derived from these activities.

Comparable burdens and ability to pay

Another general approach to emissions allocation is the sentiment, frequently stated but not subject to more detailed analysis, that allocation should affect all countries similarly or involve "comparable burdens", or "sharing the effort equally." This is not to imply that countries should incur the same monetary costs (e.g. per capita); some conceive of it as a fixed proportion of GNP (Burtraw and Toman, 1991), others in terms of a more general measure of ability to pay, including more complex measures (e.g. the Human Development Index--see below).

The Convention's principle of common but differentiated responsibilities and respective capabilities embodies elements of proportionality and historical responsibility as well as the comparable burdens/ability to pay approach.

Willingness to pay

Another principle is simply that countries should bear costs based upon what they are--or objective "should" be--willing to pay, give the potential damages they face from climate change. According to this principle, contributions should be determined by a combination of ability to pay (reflecting current wealth) and, national benefits gained in terms of reduced climatic stresses, and level of general concern about climate change.

This approach reflects the principle of welfare economics that subjectively perceived benefits ought to affect the distribution of burdens (and hence allocations). Dorfman (1991) draws the important distinction that for a common property resource (degradation of the atmosphere), willingness to pay should be based not on how a country values a given reduction in its own emissions, but instead, how much it would value a reduction in world-wide aggregate emissions. Presumably those valuing such reductions to a greater extent should be more willing to abate. This basically accords with Kant's Categorical Imperative (1785), which states that one should act as if the maxim of one's act were to become a universal law of nature. An idealized application of this Kantian Rule for abatement is analyzed by Barrett (1992) for emissions allocation.

One concern is that this could lead to a situation of "victim pays", though in the greenhouse case the wealthiest countries may be both the greatest polluters and the most willing to pay. At present an intractable difficulty is the lack of knowledge concerning the regional impacts of climate change, and in practice such a criteria would imply piecemeal negotiations in which each country had an incentive to underestimate the potential damages from climate change, and overestimate the costs of abatement, so as to obtain a lax allocation for itself.

Applications of distribution theory in welfare economics

A very large welfare economics literature exists on the distribution of income within countries, and clearly there is limitless practical experience on how countries handle distribution issues. It is an interesting question whether and how any of this analysis and experience should be brought to bear on the issue of climate change. Interestingly however, none of the climate change literature at present appears to attempt this.

Conclusions

The various approaches outlined offer general criteria, which have been most widely raised in the context of wealth and other north-south differences, but which can in principle be extended to reflect other differences. Although complex, the provisions of the Convention are consistent with or reflect a number of these approaches. Neither the Convention or these approaches, however, give specific rules to determine a unique, maximally equitable allocation of emission entitlements or abatement costs.³² We turn now to consider specific, equity-based proposals for allocating future emissions and/or abatement costs.

1768

1769 V.4 Specific emissions allocation proposals

1770

1771 This section considers proposals for fair distribution of emissions--and by implication
 1772 abatement effort--separated from any substantive financial transfers related to climate change.
 1773 The distribution of emissions / abatement effort then directly determines the payments, and
 1774 any abatement-related transfers would be similarly determined directly by the initial emissions
 1775 allocation, through the mechanisms of joint implementation or by more formal emissions
 1776 trading. The subsequent section then considers other approaches which consider directly the
 1777 question of 'who should pay' abstracted from the question of distribution of emissions.
 1778

1779 There are three reasons for dividing the issues in this way. First, it provides a useful
 1780 way of classifying the literature: although much of the general writing does not explicitly
 1781 distinguish issues of who should pay from emissions distribution, most of the more analytic
 1782 material in practice focuses upon one or other as the "output". Second, it provides an
 1783 analytically clear delineation which may help to remove some of the confusion in
 1784 understanding the literature. Much of the economics literature *assumes* that an international
 1785 market--mediated by large international transfers to produce a global least-cost response--exists
 1786 or will naturally come into being. This debatable assumption explains much of the division
 1787 between economic and other perspectives. Third, by the same token it provides a politically
 1788 useful clarification; many are skeptical of the prospects that an international fund, with
 1789 payments though it on some equitable basis on support of a globally optimal response, will in
 1790 reality ever be created, and this explains much of the fear about inequitable global responses.
 1791 Focusing initially upon allocation in the absence of separated big international transfers helps
 1792 to clarify these issues.
 1793

1794 Ad-hoc proposals

1795

1796 Various ad-hoc allocation schemes have been proposed. Krause *et al* (1993) suggest
 1797 that an overall cumulative limit for emissions of 300GtC over the period 1985-2100 be
 1798 established and divided equally between the current industrialized and developing countries.
 1799 The general characteristics of this allocation are argued to be ethically appealing--it requires
 1800 substantial cutbacks from the industrialized world and allows for some interim growth from
 1801 developing countries--but no more detailed division is offered and no more formal
 1802 justifications for a 50:50 aggregated division of future emissions are presented.³³ Westing
 1803 (1989) suggests land area as a basis for allocation, but without any particular justification and
 1804 with some perverse consequences (Grubb *et al*, 1992).
 1805

1806 More widely suggested is some proportion of GNP; Wirth and Lashof (1990)³⁴ and
 1807 Cline (1992) for example suggests that this could be a component of an allocation on the
 1808 grounds that carbon emissions are partially tied to economic activity. One difficulty is that the
 1809 relationship is quite variable between countries for a variety of reasons, and pure GNP
 1810 allocation faces the objection that on its own it would directly rewards richer, thus

1811 exacerbating inequalities (especially since poorer countries generally have lower GNP/carbon
 1812 ratios); there could also be technical difficulties associated with definitions and manipulation of
 1813 GNP comparisons (Grubb, 1989).
 1814

1815 Equal per-capita entitlements

1816

1817 The most widely cited specific proposal for allocation in the literature is that derived
 1818 directly from egalitarianism, suggesting that all human beings should be entitled to an equal
 1819 share of the atmospheric resource. This takes two general forms, with minor variations.
 1820

1821 Equal contemporary entitlements--allocation in proportion to national population--is
 1822 proposed by Grubb (1989), Bertram (1989, 1992), Epstein and Gupta (1990), and Agarwal
 1823 and Narain (1991), among others. To prevent this providing an inducement to population
 1824 growth, Grubb (1989) suggests that it should be restricted to population above a certain age.
 1825 This has been criticized for 'discriminating against children' (though of course, like all
 1826 international allocation proposals, it says nothing about distribution within countries): Grubb *et al*
 1827 (1992) note a wider range of possibilities for avoiding any incentive to population growth,
 1828 including 'lagged' allocation (related to population a fixed period earlier); apportioned to a
 1829 fixed historical date; or including an explicit term related inversely to population growth rate.
 1830 The net effect in all cases would be to give developing countries, with much lower per-capita
 1831 emissions, a substantial excess entitlement, whilst the industrialized countries, with emissions
 1832 well above the global average, have a deficit.
 1833

1834 This effect is much stronger still in proposals for equal historical or stock entitlements.
 1835 Fujii (1990), Ghosh (1991) and Meyer (1992) propose that everyone should have an equal
 1836 right to identical emissions regardless of country and generation. Fujii and Meyer take the
 1837 equability of this allocation as self-evident; Ghosh (1993) argues that it can be derived from a
 1838 range of diverse ethical principles including Rawlsianism, traditional utilitarianism, and even
 1839 libertarianism.³⁵ The general justifications for historical responsibilities in various forms are
 1840 discussed further below. Grubler and Fujii (1991) and Meyer (1992) develop detailed systems
 1841 of accounts involving intergenerational transfer of the responsibility for past excess per-capita
 1842 emissions by the industrialized countries, with the former allowing for progressive absorption
 1843 of past emissions; den Elzen *et al* (1993) apply the idea with an energy model to a total carbon
 1844 budget defined over 1800-2100. All these studies indicate that the industrialized countries have
 1845 'overused' the atmosphere in the past, and on most such approaches have built up a large
 1846 "debt", the developing countries are in "credit."
 1847

1848 Solomon and Ahuja (1991) propose that allocations should be based on "national
 1849 historical per capita emissions"--the "natural debt" index as introduced by Smith and discussed
 1850 in section III above--but do not elaborate quite what this means in terms of emission allocation
 1851 (Smith's own application of the "natural debt" concept is in terms of obligation to pay, and is
 1852 discussed below).
 1853

1854 Egalitarian allocation, in either the contemporary or historical form, would be
 1855 compatible with some of the more general principles noted above (such as Rawlsian and basic
 1856 needs) but not others (such as comparable burdens and willingness to pay).

1857 Status quo

1860 At the opposite end of the spectrum, an alternate principle for emissions allocation has
 1861 been suggested--but not necessarily advocated--for example by Young and Wolf (1992) as
 1862 "status quo"--not only that past emitters should be held harmless but that their current rate of
 1863 emissions constitutes a status quo right now established by past usage and custom. Analogies
 1864 are drawn with the common law principles of adverse possession, such as "squatter's rights".
 1865 Ghosh (1993) comments that "pollution rights have no common law sanction."
 1866

1867 It is important to recognize, however, that international law has allowed a state to
 1868 establish preferential rights to fisheries, a natural resource that is otherwise a common, limited
 1869 resource, where another state has recognized that state's long-established use and its particular
 1870 economic dependence on that resource. Whilst the law concerning the allocation of fisheries
 1871 cannot be transposed to the climate change context, it is conceivable that the general principles
 1872 of equity could be invoked to justify developed countries' use of the climate system at present
 1873 day rates, particularly in the absence of developing countries' challenges to such use (Yamin,
 1874 1994). An important general equitable principle in this regard is the principle of "estoppel"
 1875 which according to Franck and Sughrue "imposes a duty on States to refrain from engaging
 1876 inconsistent conduct vis-à-vis other States" (Franck and Sughrue 1993). A failure to address
 1877 and challenge explicitly the global basis of entitlements to GHG emissions could be
 1878 characterized as acceptance of current use levels and have significant legal implications for
 1879 establishing a basis of entitlements to GHG emissions under the Convention.
 1880

1881 A strict status quo allocation--proportionate to current emissions--would violate all the
 1882 more general principles outlined in the previous section. In fact, none in the literature appear
 1883 to advocate strict status quo as an equity principle in its own right. It has however received
 1884 widespread reference as a basis from analysts taking a pragmatic or game-theoretic approach
 1885 (e.g. Barret, 1991), in that it is the default allocation that would arise in the absence of
 1886 agreement (and hence a focal point), and the only specific allocation basis which does not
 1887 automatically impose big burdens upon the industrialized countries. In such treatments the
 1888 ethical basis, where considered, is usually referred back to concepts of equal burdens. It
 1889 should be emphasized that in this context "status quo" is not a static concept, but rather refers
 1890 to starting from a baseline of what emissions would have been in the absence of abatement,
 1891 and thus would allow for more rapid growth from developing countries.
 1892

1893 Mixed systems

1894 The number of specific, single-criteria proposals for emissions allocation is thus rather
 1895 limited. A comparative study by Burtraw and Toman (1992) also considers just the two main
 1896 dimensions of equal per-capita entitlements, and equal percentage cuts. There are of course
 1897 many other proposals which approach the question directly in terms of "who should pay",
 1898

1899 considered below. Before turning to them, an emerging theme in the literature has been the
 1900 possibility of combining different criteria.
 1901

1902 Wirth and Lashof (1990) propose allocations based on an equal (50:50) mix of population
 1903 and GDP, and Cline (1992) proposes an alternate allocation which consists of a weighted
 1904 combination of population, GNP and current emissions.
 1905

1906 A form in which historical contributions are considered as a determinant of emissions
 1907 allocation, other than historical egalitarianism, is a scheme examined by Grubler and
 1908 Nakicenovic (1991) in which countries have to cut back from current levels in direct
 1909 proportion to their responsibility for past increases. In a sense therefore this is a mixed system.
 1910 In requiring cutbacks from all countries--albeit more from the richer countries--it is probably
 1911 inconsistent with the other principles sketched in the previous section (though modifications
 1912 could be considered to address this).
 1913

1914 Grubb and Sebenius (1992), supported by Shue (1993), examine a mixed system in more
 1915 detail, and an almost identical formulation was proposed independently by Welsch (1993).
 1916 These authors suggest an allocation which combines egalitarian and status quo / comparable
 1917 burden principles, in the form of a combination of population and current emissions, but do
 1918 not specify an equal weighting of these components. Rather they argue that the weighting
 1919 accorded to population should increase over time towards a more pure per-capita allocation.
 1920 Grubb and Sebenius suggest that the weighting would have to be determined on the basis of
 1921 negotiation, reflecting partly the strength of competing equity arguments employed; Welsch
 1922 proposes a 50-year transition from current emissions in the year 2000 to per-capita allocation
 1923 in the year 2050, and presents sample calculations of the distributions of the costs this could
 1924 involve.
 1925

1926 V.5 *Proposals for distributing abatement costs including international transfers*

1927 The proposals in the previous section focus upon "fair" approaches to distributing
 1928 emission "entitlements"; financial transfers are considered insofar as they might arise from
 1929 exchanging these entitlements. Most analysts suggest that both equity and efficiency
 1930 considerations suggest a case for large international resource transfers as part of any regime for
 1931 substantial reductions in greenhouse gas emissions, and some treatments focus upon this
 1932 explicitly.
 1933

1934 Three main approaches have been taken to consider how, and how much, such transfers
 1935 might occur.
 1936

1937 V.5.a *Basis of the Climate Convention*

1938 One is based upon the principles in the Framework Convention on Climate Change.
 1939 Concerning paying for abatement, the Convention effectively divides Parties into three groups.
 1940 Annex 1 countries (all the industrialized countries) are expected to bear their own abatement
 1941
 1942

costs. Those also listed in Annex II (industrialized countries minus those with economies in transition) agree in addition to fund the efforts of the third group, developing countries. The Convention states that Annex II countries: "... shall provide new and additional financial responses to meet agreed full costs incurred by developing country Parties" in preparing reports under the convention (Article 12), and "shall also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the full incremental costs of implementing measures that are covered by paragraph 1 of this Article and that are agreed [between that country and the funding agency]."

This wording was very delicate; exactly how the term "agreed full incremental cost" is to be interpreted, and just who has to agree and how, is a question that is exercising the minds of experts in many different countries and Institutions, and which raises both process and outcome equity issues in its own right. The concept of incremental costs does not imply anything about the level of abatement developing countries are to achieve and as yet there is no clear agreement about its meaning and application to specific situations. Some of these issues will need to be addressed by the Convention's Conference of the Parties including a number of procedural equity issues relating to the structure, interim nature and independent operation of the Global Environment. Facility as the interim financial mechanism of the Convention.

In addition to the financial and other resource flows through the financial mechanism, a number of countries have proposed using the Convention's provisions on joint implementation to permit a second avenue of funding and technology to assist abatement efforts in developed and developing countries. The concept of joint implementation via offset investments in third countries and the concept of tradable permits or "entitlements", which are the subject of strenuous debate at present, are considered further below.

V.5.b Transfers determined by emission allocation and tradable entitlements

This second approach to international transfers is to let them be generated directly by determining a fair initial allocation, and allowing these "entitlements" to be traded (UNCTAD, 1992).

The initial allocation would be the principal means of determining resource transfers. Since most of the allocation proposals noted above would give poorer countries entitlements greater than their needs, and leave richer countries with a deficit, this would generate a transfer of resources to the poorer countries. The "outcome" equity issues involved thus parallel those noted above in discussing emissions allocation; indeed, many of the specific allocation proposals noted were only advanced in the context of them being *initial* endowments as the starting point for such a tradable entitlement system, on the ground both that this would both be more efficient and the only feasible way of introducing allocations radically differing from current emission patterns.

A number of concerns have been raised about practical and legal aspects of such systems, including their possible fairness in operation without institutional safeguards. Several analysts,

including both those supporting and opposing tradable entitlement schemes, have raised concerns about the legal and equity implications of allowing countries to sell forever and "right" to emit (Yamin, Joint Implementation and the Framework Convention on Climate Change: Legal, Institutional and Procedural Issues, 1993). For this reason, it has been proposed that entitlements should be either leasable (Grubb 1989; Agarwal and Narain 1991), or issued with a finite lifetime (probably overlapping) and reissued periodically according to the agreed allocation scheme (Bertram 1992; Grubb and Sebenius 1992). Negotiating and overseeing any such system would also involve a range of other process equity issues parallel to those considered below.

V.5.c Direct payment accountability approaches

The third approach is to seek a basis directly to determine "who should pay" for abatement, rather than to treat this as a consequence of future emission allocations. To a large extent the general equity issues involved parallel those involved in considering fair emission allocations, with ideas based for example upon interpretations of Rawlsian criteria, equal burdens, and willingness to pay. But the limited literature addressing the question in this form places relatively more emphasis upon two other components: *responsibility* for emissions, often including past emissions; and *ability* to pay for abatement. Smith *et al* (1993) draw this distinction directly in terms of indices of historical responsibility and ability to pay; Grubb (1990, pp. 281-286) draws a more general distinction between *responsibility-based* and *burden-based* criteria.

Polluter pays principle

A general basis for responsibility may be considered in terms of the Polluter Pays Principle. The OECD formally adopted a form of polluter pays principle in 1974 as a guide to environmental policy in stating that if measures are adopted to reduce pollution, the costs should be borne by the polluters. In particular, the costs:

"... should be reflected in the cost of goods and services which cause pollution in production and/or consumption. Uniform application of this principle... would encourage the rational use and the better allocation of scarce environmental resources and prevent the appearance of distortions in international trade and investment." (OECD Council, 14 November 1974 C(1974) 223, Paris, 1974).

This is an economic principle which is essentially concerned that polluters should bear the costs of abatement without subsidy. The principle does not explicitly state that all polluters of a common pollutant should pay in proportion to their emissions, and in fact the literature seems remarkably opaque about how the principle should be applied in a context like climate change. The principle clearly points towards responsibility-based rather than burden-based criteria, proportional in some way to emissions: the polluter should pay; but on what basis, who should receive and for what purposes?

A critical distinction that is rarely clarified is whether the principle applies to *gross* payment or *net* payment. Burtraw and Toman (1991) assume that it applies to net payments, so that each country should pay for *abatement* in proportion to its contemporary emissions: this, they note, would be "regressive against national income, a characteristic that is bound to spark developing country opposition", and Chichilnisky and Heal (1994) and others have pointed out that such allocation of payment may be neither efficient nor fair. Other authors assume that the principle means that gross payments should be proportional to emissions, leaving the question of how the resulting revenues should be distributed as a separate question of efficiency and equity; and they also consider different bases for payment as now discussed.

Historical responsibility and natural debt

Smith *et al* propose that responsibility for paying should be determined on the basis of the 'natural debt' index described in section V.3; i.e. in proportion to total cumulative emissions since a specified date. Because this in itself would result in all countries bearing some responsibility for paying (though very much less for developing countries), they modify this by suggesting a lower threshold for "basic needs" emissions, consistent also with the arguments of Agarwal and Narain (1991) and others.

The principle of using cumulative historical emissions directly as a component in determining payment (or future emissions allocation) is considered by these authors as a natural and important matter of equity, and many others also argue the central equity importance of historical emissions in more general terms. Some of these authors recognize a variety of potential practical difficulties: how far back the emission estimates should go; whether and if so how the natural decay (reabsorption) of emissions should be taken into account; which gases should be included, given the highly variable quality and in some cases complete absence of data; and how to relate the emissions to scale (e.g. cumulative population - if so how defined - or current population, etc.). In part this reflects different potential definitions of the "natural debt" concept; in assessing responsibility indices, for illustration Smith *et al* consider total industrial CO₂ emissions since 1950 by country, with a range of lower threshold levels. However, at the same time as espousing the Fujii formulation of intergenerational egalitarianism, Ghosh (1993) criticizes the 'natural debt' concept as a basis of historical responsibility on the grounds that it is an abstract, environment-centered focus which 'does not acknowledge responsibility to others for one's actions .. does not relate to fairness across human beings'.

Historical responsibility as an equity principle has strong support in the literature and politically in developing countries (see for example the Hyder quote in section V.3 above). However, Young (1990), Kaspersen and Kaspersen (1993), and Grubb *et al* (1992) note three counter-arguments about the equitability of what the last of these characterize as 'making present generations pay, by virtue of their geographical location, for the activities of previous generations' in that country:

- past generations were largely unaware of the consequences of their actions and had no incentive to limit emissions (this issue has some analogies with the issue of strict versus fault-based liability in legal regimes);
- it is not always clear who has benefited from historical emissions, given that the patterns of production, trade, consumption and migration shift over time and are intricately interwoven. Boundary changes could also create major difficulties for allocating past emissions to current states in some cases (as with recent changes in Eastern Europe).
- although development has generally bequeathed the greatest benefits to descendants in the same country, important benefits have spread much more widely. Positive externalities associated with development (e.g. accumulated knowledge) as well as negative ones (such as pollution) can be transmitted both internationally and intertemporally.³⁶

In response to some of these criticisms, Smith *et al* (1993) argue that it is not only equitable but also that 'we are asking the present generation to take responsibility for the future .. if we dismiss historical responsibility, what is to keep the next generation from doing so?'; or as Hayes puts it in the same volume, 'the current generation of leaders cannot disavow its obligation to pay off its natural debt .. at the same time as it claims to be adopting the principle of intergenerational equity'. Ghosh also rejects objections to historical responsibility as partly inaccurate,³⁷ but mostly irrelevant to the Fujii principle of equal historical per-capita entitlements since it is based not upon fault, blame or compensation but upon an egalitarian principle of access.

These debates, and the different elements noted in the quote from Hyder above, illustrate several different dimensions to the debate about historical responsibility. A clear statement by Bhaskar (1993) links several of these themes and lays the prime emphasis on the fact that 'the current generation [in developed countries] are the prime beneficiaries of resource transfers from previous generations .. developing countries have a claim to part of the transfers, simply because they were made possible by the excessive use of global environmental resources in previous generations in the developed countries .. if the current generation accepts assets from their parents, then it is incumbent upon them to also accept the corresponding liabilities'.

Grubb *et al* in turn note the curious feature that in such reasoning, a 'primary justification of consideration *historical* emissions is based upon *current* wealth. And it is intended to compensate for *future* increased costs to developing countries, if they are constrained'; they add hopefully, "tentatively, we suggest that the ethical divide between historical criteria and those focused upon current emissions and current relative ability to pay may not be as large as it appears."

2117 Incorporating Ability to Pay

2118
2119 In addressing the question of "ability to pay", several authors have made reference to
2120 GDP, or the UN Scale of Assessments. Smith *et al* suggest an ability to pay element which is
2121 proportional to GNP (on a Purchasing Power Parity basis) for all countries subject to a
2122 threshold value, determined by Morris's Physical Quality of Life Index (PQLI);³⁸ countries
2123 with a PQLI below this threshold would be exempt.

2124
2125 On the basis of this, the authors argue that countries should have an 'obligation to pay'
2126 based upon the two elements of historical responsibility and ability to pay (both with lower
2127 thresholds). They suggest that equal weight be given to these two components and observe that
2128 the resulting obligation to pay could be either the product or the sum, favoring the latter.

2129 Utilitarian formulation

2130
2131 A wholly different quantified approach to the question of who should pay for abatement is
2132 provided by Chichilnisky and Heal (1994), who apply the concepts of classical economics to
2133 construct a strictly utilitarian formulation that seeks to maximise the sum of utilities across all
2134 countries, i.e., aggregate world utility, however, one recovers the classical solution in which
2135 marginal abatement costs are equalized at efficient allocations. In this case, only certain ways
2136 of distributing a given total emission entitlements between countries are efficient. The
2137 orthogonality between distribution and efficiency so central to the welfare economics of
2138 markets for private goods is not a characteristic of markets for environmental public goods. As
2139 noted above, these authors noted that in a situation without international transfers, efficient
2140 marginal abatement costs would vary between countries. If unrestricted lump-sum transfers are
2141 allowed, however, to recover the classical solution in which marginal abatement costs are
2142 equalized to achieve efficiency, only certain distributions of payment can maximise the
2143 aggregate utility. Specifically, they show that for the case of two countries in which both have
2144 the same standardized utility function (i.e. both value a given consumption level (and
2145 atmospheric quality) equally), then:

2146
2147
2148 "At a Pareto efficient allocation, the fraction of income which each country
2149 allocates to carbon emission abatement must be proportional to that country's
2150 income level and the constant of proportionality increases with the efficiency of that
2151 country's abatement technology."

2152
2153 This is the only distribution of abatement effort, for a given global total abatement and set of
2154 welfare weights, in which no country can be made better off without making another worse off
2155 (note however that it can only define relative contributions between different countries when
2156 the weights assigned to welfare in each country are specified).³⁹ The result in turn implies that
2157 the total resources each country should put towards abatement would increase as the square of
2158 the national income. The paper implies (but does not prove) that a similar conclusion would
2159 hold for the more general case of other utility functions (provided these are still similar
2160 between countries) and more countries.

2161

2162 Application of funds and transfers

2163
2164 These efforts to address questions of who should pay still do not address the question of
2165 who should receive for what purposes. Smith *et al* imply that the payments they consider
2166 would go to an international fund which would then be used to finance abatement at the lowest
2167 marginal cost, wherever that might be, to the degree determined by total abatement specified.
2168 In applying this index to evaluating transfers however, Hayes (1993) develops crude aggregate
2169 cost curves which combine abatement costs with protection against sea-level rise (but not other
2170 components of adaptation), aggregating Northern and Southern blocs. Combining this index
2171 and cost function leads him to conclude that 'the incremental cost of abatement and coastal
2172 protection in the South that is justifiably the responsibility of the North' is a few tens of
2173 billions of dollars annually (in doing so, he draws upon the transboundary impacts as part of
2174 the justification for using historical impacts; this as noted is an important but distinct ethical
2175 issue from that of paying for abatement). Chichilnisky and Heal (1993) also imply that
2176 expenditures would be directed towards the global least-cost options wherever they may be.

2177

2178 V.6 International trade and the incidence of abatement costs

2179

2180 The above analyses all focus upon highly simplified pictures of the abatement problem, in
2181 which the only interrelationship between countries is the impact of greenhouse gas emissions
2182 and deliberate financial transfers associated with paying for abatement (or, in the context of
2183 section 5.3, adaptation). In reality, abatement involves actions that affect the consumption of
2184 many goods that are traded internationally and this in itself has other indirect consequences.

2185

2186 One concern expressed has been abatement action by the industrialized world will itself
2187 indirectly harm developing countries by slowing economic growth and thereby lessening
2188 demand for a variety of traded goods from the developing countries. Given the modest
2189 estimates of the impact of abatement on economic growth rates (at least for abatement to the
2190 degree currently being considered; see abatement cost chapter) it is likely (but remains to be
2191 demonstrated) that this second-order effect would be negligible compared with two other
2192 international effects. One is the ultimate benefits from reducing the rate of climate change
2193 itself, which for the reasons discussed in this chapter are likely to be greatest for the
2194 developing countries. The other is the impact mediated through the effect on the traded volume
2195 and price of the commodities which give rise to greenhouse gases--particularly fossil fuels.

2196

2197 This latter factor may introduce substantial variations between countries, depending on how
2198 restrictions are applied. If--as is generally assumed--abatement policies are applied to
2199 consumption, the likely effect is to reduce the internationally trade volume and price of coal
2200 and (to a lesser extent) oil. This effect will tend to benefit net importers of these fuels and
2201 reduce the revenues to fossil fuel exporters (see chapter on abatement costs). More generally,
2202 'the relative value of non-fossil energy resource would be increased; that of high carbon
2203 resources decreased' (Grubb 1990, p.285). Extensive abatement efforts could thus have serious
2204 implications for those countries that depend heavily upon coal exports or (to a lesser extent) oil
2205 exports--an equity issue already raised in international discussions.

2206

The effects are however complex particularly concerning oil. Firstly, one initial response to reduce CO₂ emissions could be to burn more fuel oil in power stations in place of coal. Furthermore, gas--which in power stations emits about half as much CO₂ as coal--is very likely to be favored in CO₂ abatement strategies, and gas resources are often associated with oil deposits (gas is also associated with many coal mines). The overall impact also depends very much on the time horizon considered. Heal (1984) noted that in general, aversion to climatic risks would tend to flatten the use of carbon resources over time: peak and initial usage would be lower, but usage would also fall more slowly, partly because the resource base would be extended over time. Manne and Rutherford (1994) provide a more detailed energy analysis, concluding that 'carbon restrictions tend to depress oil prices in the near term, but to increase them in the long term .. oil is less carbon-intensive than coal-base synthetic fuels, and hence oil enjoys a premium'; they also find that carbon restrictions improve the prospects and price for gas exports.

Such indirect impacts of abatement on fossil fuel exporters (and importers) are thus potentially important, but are frequently not simple.

V.7 North-South Joint Implementation

Joint implementation has emerged as one of the major debates in the post-Rio negotiations. The term is generally applied to the idea that industrialized countries might invest in projects in other countries, particularly developing countries, that displace greenhouse gas emissions. Industrialized countries consider that the main incentives arise if some or all of the emission savings can be credited towards the donor country's emission target, and many economists tend to see JI as a natural way of improving economic efficiency, by allowing industrialized countries to invest in abatement wherever it is cheapest.

North-South JI involves project-level investment, appraisal and crediting of emission savings by a "donor" country on the territory of a "host" country. This involves a host of equity issues that underpin the political debate, many of which illustrate equity issues discussed in this chapter (Note that NSJI contrasts sharply with proposals for international tradable permits, in which the equity issues would arise primarily (though not exclusively) from the allocation of initial emission rights between legally equivalent parties; Dubash (1994) explores the many differences and argues that NSJI is an attempt to lower the political costs associated with allocating tradable permits, "at the price of higher social and environmental costs").

A number of technical and economic concerns about NSJI have been raised, particularly concerning the problems associated with fact that savings have to be measured against a "counterfactual" baseline (i.e. an estimate of what would have happened in the absence of the JI project - what is to prevent inflated baseline estimates or other gaming behaviour?) and uncertainties about project success (who has the responsibility for project success, and what happens if it fails?), and administrative costs arising from both these factors; reviews of these technical issues are given by Loske (1994) and Selrod and Torvanger (1994), the latter being much more optimistic than the former, and in a number of books and conference proceeding

(e.g. Kuik et al (1994), Ramakrishna et al (1994)). Here however the focus is upon the underlying equity issues, which can be classified along the lines set out in this chapter.

Allocation issues

Analysts have raised the following concerns about the implications of NSJI for emission abatement responsibilities and associated costs.

- NSJI could impose hidden administrative and/or opportunity costs upon host countries which are only partly recovered through the investment itself (Maya, 1994);
- NSJI could "cream skim" the cheapest projects, so that if and when developing countries are required to adopt emission constraints in the future, they will be faced with higher marginal abatement costs (e.g. Parikh 1993, and many others);
- if NSJI allows industrialized countries to continue increasing their own emissions it will perpetuate - and perhaps even exacerbate - global inequalities in per-capita emissions rather than tending towards any long term convergence (Parikh 1993, Loske 1994, and others);
- by reducing the pressure on ICs domestic action, NSJI may reduce the pressure for technical advance and innovation that could lower costs for all in future abatement (Loske 1993), which may itself differentially increase the future costs to developing countries (Ghosh 1994).

To each of these concerns there are responses that it depends (in part at least) on how the framework for NSJI is defined, and on how future commitments are structured to take account of any previous JI activity (e.g. Jones 1993, Vellinga and Heintz 1994, Heintz *et al* 1994, Metz 1994, Ghosh 1994). This however does illustrate that JI does not really overcome the basic political issue of allocating future emission rights, though it delays (at the expense of complicating) the need to address this core equity issue concerning the role of developing countries.

Efforts to address the technical and allocation issues also highlight concerns about more procedural equity issues. Since JI a project cannot (or is unlikely to) proceed without the consent of the host country, inadequate state participation per se is not a primary matter of concern, but issues of information and power asymmetries are raised in the literature. Concerning information:

- donor countries tend to have a far greater research and analytic capability, so they have a comparative advantage in any negotiations about framing JI projects (Pachauri (1994) comments that "the biggest apprehension that exists on the issue

of JI relates to small countries that lack the capacity to evaluate the implications of specific projects”);

- hence the lack of analytic expertise may lead to host countries accepting projects that later prove to be against their interests.

Concerns about power asymmetries include:

- developing countries may find themselves pushed into projects on disadvantageous terms because of the balance of economic power; short term financial pressures, for example, could lead to host countries giving up land to JI projects that could have far greater productive use for the host country in later years (Maya 1994);
- JI projects may be driven by the interests of technology suppliers in the donor countries, perhaps at the expense of indigenous equipment manufacturers (Maya 1994).

Again, protection against at least some of these potential inequities can be developed, with the emphasis in the literature being upon the need for an open, transparent and multilateral framework for JI agreed between Parties to the Convention (e.g. Ghosh 1994, Markandya 1994), and also projects that meet a range of development needs (Imbree 1994).

Others, however, express concern that such an extensive multilateral framework may involve such high administrative costs as to render the idea impotent. And, conversely, it could be considered inequitable to expect industrialized countries to engage in stronger commitments whilst barring them from exploring alternative ways of achieving the same global environmental benefit; therefore, there is also an onus upon developing countries to clarify their concerns so as to allow a basis for a regime that is considered fair and practical by all parties. The purpose here however is not to argue for or against NSJI, but to illustrate the central place, and range, of relevant equity issues in any practical moves towards transnational implementation of measures to address climate change.

VI Equity Within Countries

VI.1 Introduction

This section examines issues within countries. Not only is this important in its own right, it can also shed a new light on the issues discussed in the other sections of this chapter.

- As remarked earlier (pp. 16 and 17 above), institutions to address a wide range of common interests exist primarily within countries, and equity is an important influence and measure of the strength and perceived legitimacy of these institutions. Although, the nature and strength of these national institutions is far from uniform, yet they provide the main working model for incorporating equity into international relations.
- A national focus allows lessons to be drawn from the experience of economic reform programs, especially the structural adjustment programs in Southern countries, but also programs of economic restructuring in industrialized as well industrializing countries.
- Unless intra-national equity issues are addressed explicitly, it may be impossible to mobilize public opinion for amelioratory action in both developed and developing countries as it is only at the intra-country level that we can begin to explore non-technocratic approaches to collective action.
- It is only at the intra-country level that we can begin to explore non-technocratic approaches to collective action.
- Since policies and actions to combat climate change would in any event begin at the national level, the examination of intra-country considerations could help individual countries by clarifying the range of issues involved.

Having said this, however, it must be acknowledged that intra-country equity does not figure (except obliquely, see p. 3 above) in the Framework Convention on Climate Change. It is being introduced here to facilitate the search for optimal national and international policies. It is not its purpose to introduce an entirely new element into international negotiation. Nor is its purpose to side-step the central concern of the Convention and also of this chapter--the issue of international equity and differentiated responsibility. Nor indeed is the intention to legitimize a new period of colonialism in which the scope for sovereign national action is restricted unduly by international agreements on the nature and form of intra-country equity.

As mentioned earlier, equity considerations have become a part of climate change discussions primarily because of the awareness of the diverse situation of both countries and individuals--not only in terms of their contribution to climate change, but also of the impact of the change on their well-being, their individual and collective capacities to cope with this

impact, and on their abilities to undertake mitigating action. Furthermore, there is also a growing awareness that the combination of large-scale changes and iniquitous arrangements will necessarily lead to conflicts and even wars, which will further aggravate the adverse effect on social well-being. Finally, it is also acknowledged that the burden of mitigation must not be placed disproportionately on the poor and vulnerable groups.

The above considerations have influenced decisions in a number of areas. In addition to the agreement to limit emissions to minimize the magnitude of the change, there is also an emerging consensus on the need to compensate the worst affected groups and countries, especially the small island states. Third, is the support, through Agenda 21, for the strengthening of coping systems in vulnerable countries. The agreement to distribute the burden of mitigation in an equitable manner also falls into this category. Finally, the awareness of the need for adjustment has also led some to recommend that countries should begin addressing major sources of inequity.

This can be stated differently. Equity considerations are germane to the climate change issue in two different contexts--equitable distribution of the costs (or benefits) of the change, and equitable contribution to amelioratory and preventive actions. Neither experience is without precedent in national contexts. There is an extensive literature on the distributional impacts of the business cycles, supply shocks (e.g. the oil price increases in the 1970s), economic development, and episodes of structural adjustment and liberalization. In all such cases, the questions are similar to the ones begin raised in the present situation, namely how is the burden of the change to be shared, and who should pay for amelioratory or preventive actions. This literature can be divided into two groups, that which looks at governmental policies within a given institutional context, and that which examines the institutional context itself. In addition to this, there is also a theoretical literature on conditions that will give rise to equitable outcomes within countries.

VI.2 Policy oriented literature

The classic example of policy oriented literature is the UNICEF publication on structural adjustment in Southern countries, *Adjustment With a Human Face* (Cornia, Jolly, and Steward 1983). As the subtitle of this text makes clear, the object of the exercise is to protect the vulnerable while maintaining growth. This book is a part of a critique that emerged in the 1980s against the then conventional approaches. Since then, the critique had gradually come to represent the new mainstream position.

Structural adjustment or 'stabilization' becomes necessary when the aggregate expenditure (or consumption) of a country begins systematically to exceed its aggregate income; the result is the accumulation of debt at an unsustainable and unserviceable rate. In the 1970s, these difficulties were seen as part of the short-term problems of cyclical fluctuations, and were responded to with the short-term measure of stabilization, on the pattern of similar problems and policy responses in Northern countries. Subsequently, it was recognized that the problem was of a longer-term duration and structural rather than cyclical; in other words, the problems emerged not because of the normal functioning of a business

cycle, but because the economic and political structure of some countries was designed to produce these results on a systematic basis. In either case, the symptoms were a growing public debt, deficits in government budgets and international payments, and accelerating inflation.

In the absence of a policy response, these symptoms were likely to be cured through the 'classical adjustment' mechanism, in which the debt squeeze brings about an economic contraction and thus a reduction in expenditures. Since Keynes (19??), this has been recognized as an sub-optimal path because of its high social and economic cost. The main policy response in the 1970s and 1980s was that of a managed economic contraction through budget cuts (especially on such 'non-essential' items as social services, consumer subsidies, and general administration), reduction in domestic credit, devaluation, and the liberalization of foreign trade and payments regimes (see Banuri 1992).

The performance of these policies have come under considerable scrutiny (see e.g., Taylor 1997, Banuri 1992, Comia et al 1983). Earlier critics argued that the orthodox adjustment programs were both ineffective and unnecessarily painful. They proposed heterodox, or supply-side approaches, which aimed to increase production directly through investment promotion, labor training, direct export promotion, and income policies. While many of these recommendations are extremely sound, experience shows that they have to be combined in varying proportions with orthodox demand contraction policies. Also, the hope for a win-win solution, in which the costs of adjustment would be avoided altogether has not been vindicated by experience. The economics profession appears to have come to the conclusion that some degree of economic contraction was inevitable during structural adjustment, if only to dampen the inflationary expectations built up during periods of prosperity.

As a result, attention of many of the critics shifted to the protection of important areas during such contraction. These critics argue that the conventional approach is sub-optimal, in that it leads to the marginalization and immiserization of vulnerable groups,--women, children, the poor, the rural population, labor, and the aged population--who are forced to carry a disproportionate burden of the adjustment. As part of their argument, Comia et al documented successful cases in which government policies managed to protect vulnerable groups while bringing structural adjustment. The result of these studies has been a remarkable turn-around in the conventional wisdom on structural adjustment. From a situation of almost total neglect of the social sector and vulnerable groups in the 1980s, current policies include the protection of these sectors and groups as integral elements of structural adjustment programs.

However, even the modified approach, which seeks to incorporate social and equity concerns, has not been without its critics. A number of writers have suggested that government-directed and targeted programs are not successful in alleviating poverty or delivering social services in many contexts. This criticism has been launched in particular by the Public Choice Theory school (Buchanan et al, 19??, Krueger 19??), and has been accompanied by calls for privatization and de-regulation. Other critics have used similar

arguments to recommend institutional development programs. We shall take up some of these criticisms in the next sub-section.

The analogy of structural adjustment to climate change is quite striking. The climate change threat has also emerged because the aggregate consumption of certain materials (mainly fossil fuels) by the entire planet has begun systematically to exceed sustainable levels. In this case, there is the accumulation of global warming gases in the atmosphere, again at an unsustainable rate. The analogy of the classical adjustment mechanism is the ecological homeostasis, which may bring about a new planetary equilibrium albeit with far fewer humans and after the payment of a very high human and social cost. The Framework Convention on Climate Change is analogous to an agreement to undertake a structural adjustment program.

In other words, the experience of structural adjustment in Southern countries has many lessons to offer for the foreseeable adjustment both at a global level and in Northern countries.

- The first lesson is that 'blind' or neutral policies have not performed well. As a result, the need to protect the social sector and some targeted groups has become widely accepted. In the climate change context, this means that such 'blind' policies as a carbon tax, or even tradable permits will have to be supplemented with policies to protect vulnerable groups and vulnerable sectors.
- In general, the experience of structural adjustment shows that policy responses need to be sensitive to economic, political, and institutional contexts of various countries. Reliance on a formulaic approach has often been ineffective if not counterproductive.
- The experience with heterodox approaches to stabilization suggests that these need to be combined in varying proportions with the orthodox, demand-contraction policies. In the climate change context this means that pure win-win solutions based on technological optimism--namely the expectation that technological improvements alone will suffice to reduce emissions to sustainable levels--are unlikely to produce the desired results unless combined with steps to reduce aggregate consumption.
- Another lesson is that in many cases even the modified approach may be deficient unless accompanied by institutional strengthening programs.

Structural adjustment and stabilization are, however, the most recent of the many arenas for the debate over equity concerns. As is apparent from the above remarks, the experience of stabilization was not restricted to Southern countries. In industrialized countries, similar questions have been discussed in the context of business cycles and stabilization. More generally, the discussion of trade-off between equity and growth also falls in this category.

In this context, equity has been taken to mean income distribution. There is a literature on the appropriate index to be used to measure income distribution. Starting with the Lorenz Curve, and the Gini co-efficient, a number of improvements were proposed. The Gini

coefficient is an index of the inequality of relative income shares, with zero representing complete equality, and one representing complete inequality. Subsequently, attention shifted to other indicators, such as absolute poverty, measured in terms of the number of people below a nutrition-based poverty line and quality of life (see Morris 1979), and basic human needs, namely education, food, health, water supply, sanitation, and housing (see e.g., Streeten 1981).

The conventional view on the relationship between equity and growth was derived from Kuznet's (1955) observation of an inverted-U relationship (the Kuznet's curve) between GNP per capita and the Gini coefficient. This observation was based on both time series and cross-section data. However, subsequent studies have added substantial qualifications to this result (see e.g., Ahluwalia and Chenery 1974).

The thrust of these arguments is that economic development and structural transformation affect income distribution within countries in specific ways. The earlier view was that income distribution would worsen with economic growth before getting better. However, the more recent evidence suggests that the pattern of change is sensitive to policy choices and institutional conditions in individual countries. Countries that followed pro-active policies, and favored investment in social sectors (education, health, social welfare) were able to pursue economic growth and social development simultaneously. In other words, at least insofar as the experience of development is concerned, a win-win solution is possible. There are, however, considerable differences over the contributing factors to win-win solutions. Neo-liberal writers (e.g., Balassa 1977, Krueger 1977) attribute the success of newly industrializing countries to market-based, outward-oriented policies. Others look to institutions of governance as key elements (see e.g., Wade 1977, Alam 1977, Banuri 1992, ESCAP 1994).

VI.3 Institution Oriented Literature

The common element of the above analyses is their rootedness in a technocratic approach to problem solving. As a result, they are focused on what the government can or cannot deliver, either in terms of policies or of outcomes. Dirigistic arguments favor direct interventions by centralized states, in the form of government investment, protection of domestic economic activity, social cost benefit analyses, and others. Even neo-liberal arguments that favor market-based approaches, view the government as virtually omnipotent in bringing about the structural transformation towards a free market economy.

An alternative to this approach is the literature that takes governance as an entry point to the analysis. It covers a broad range of ideas, including capacity building and technical assistance (UNDP 1993), community participation and empowerment (Khan, 1977), people centered development (Korten 1977), sustainable development (Banuri et al 1994). Its unifying theme is the emphasis on collective action and development of institutional and decision-making capacities. At smaller units of aggregation, this focus leads to the analysis of participation, empowerment and community development. At the middle level, it translates into the argument for the strengthening of various organs of civil society, including institutions

2551 of education, research, and monitoring. At the governmental level, the focus is on
2552 administrative reform and capacity development.

2553
2554 The relationship of these approaches to the climate change debate on equity issues
2555 derives from the analysis that lies behind them. The main idea is that inequitable outcomes are
2556 produced by institutions that fail to protect the rights of vulnerable or marginalised groups in
2557 society. Similarly, countries cannot take advantage of global opportunities, or suffer
2558 disproportionately from adverse global processes, if they lack the institutional capacity to
2559 protect their interests. Finally, countries that exhibit superior performance on one indicator of
2560 social welfare, also perform better on virtually every other indicator. This means that rather
2561 than trade-offs between different goals, there is a clustering of performance along various
2562 goals. This can only be explained by institutional factors that favor some countries over
2563 others. The solution for countries that perform poorly is to enhance their institutional capacity
2564 to protect national their rights, and more generally to pursue collective goals. Analogously,
2565 the solution for weak or marginalized groups is also to enable them to make collective
2566 decisions and protect their rights.

2567
2568 This provides a somewhat different slant on the literature cited earlier. It could be
2569 argued that the need for structural adjustment arises when the sum total of property rights
2570 exceed the available aggregate endowment of assets or resources. The solution is then to
2571 reduce the command over goods and services by re-allocating or eliminating some property
2572 rights. These might include the rights of the government (generated through money creation),
2573 or those of groups favored by distributional policies or subsidies, or even of investors who are
2574 allowed to borrow at highly subsidized rates. The argument of the critics is that in this
2575 reallocation of rights, it would be difficult for the vulnerable groups to protect themselves,
2576 partly because of their very weakness, and partly because many of their rights are likely to be
2577 informal in character.

2578
2579 One strand of this argument has been made by Sen (1976, and various others) in terms
2580 of 'entitlements.' In Sen's approach, crises, such as famines occur not because of a shortage
2581 of food, because of a failure of entitlements, namely rights to commodities. However, as
2582 Gore (1993) has argued, in much of his work, Sen focuses on entitlements conferred by the
2583 formal legal system. Although in the examination of intra-family distribution (Sen 1984) he
2584 extends the analysis to include informal entitlements as well, this does not seem to have
2585 affected the exclusive focus on the formal legal system in the remaining corpus of his work.

2586
2587 Be that as it may, two points are significant in this debate. First, that it may be more
2588 germane to look at property rights, whether formal or informal, rather than consumption or
2589 production patterns alone. Second, that there is an inter-relationship between economic and
2590 ethical considerations. As Gore points out, "for Sen, policies to counter hunger and famine
2591 must ultimately be justified through foundational arguments about what is valuable. Equally,
2592 ethical assessment of institutions, such as property rights, requires empirical analysis of causes
2593 and effects' (Gore 1993: 430).

2594

2595 From this perspective, the development process appears as a trend towards the
2596 formalization of property rights, and in many cases the expropriation of the customary rights
2597 of local communities in favor of centralized states. This was justified on the grounds that it
2598 would facilitate the pursuit of national goals, such as development or equity. The institutional
2599 perspective would argue for the reconstitution of local property rights, in order primarily to
2600 enable the protection of the rights of vulnerable communities.

2601

2602 These considerations are relevant for the examination of climate change issues. Insofar
2603 as the climate change issue is also one of property rights (or entitlements) exceeding the total
2604 endowment of planetary sinks, the response will include necessarily a curtailment of aggregate
2605 entitlements. The result is that blind policies are likely to re-allocate the property rights in an
2606 inequitable manner by curtailing the entitlements of the poor disproportionately. This is true
2607 for countries as well as groups within countries. Given the fact that the South will be affected
2608 more by climate change, that it has lesser flexibility, is closer to subsistence, and lacks the
2609 institutional infrastructure to protect lives and livelihoods, its rights will be curtailed
2610 disproportionately in any adjustment episode. The same is true of groups within countries:

2611

- 2612 • The recent cyclone in Bangladesh killed 130,000 people, while the hurricane
2613 Andrew of the same intensity killed 34 people in the US.
- 2614
- 2615 • At an individual level, the choice of protecting the rights of various people will be
2616 influenced by cultural arrangements, which favor men over women.
- 2617
- 2618 • In most countries, declines in food availability will fall disproportionately on the
2619 politically weaker and relatively passive groups, on the poor, the children, women,
2620 older people, the unemployed, and the rural people.
- 2621
- 2622 • Not only is this likely to produce conflict, the emergence of conflict will further
2623 discriminate against the weaker and more pacific groups (Suliman 1992).
- 2624
- 2625 • Major technological or political changes in agriculture result typically in
2626 expropriation of tenants and landless poor. These were sought to be offset through
2627 land reforms, which have had only limited impact (Moyo 1994, Sobhan 1993).

2628

2629 Equally, while there is rhetorical support for amelioratory actions, often only at elite
2630 levels, this has neither translated into a broad legitimacy of concerted state action in
2631 industrialized countries, nor into change in behavior towards more conservationist patterns.
2632 Similarly, the awareness of the primary responsibility of the North for the ecological threat
2633 seems to have absolved the affluent groups in Southern countries of their responsibility to
2634 respond to the threat.

2635

2636 In other words, it may be idealistic to expect that the nation-state as currently
2637 constituted will produce equitable outcomes in the face of disasters, large scale dislocations,
2638 and in terms of the response itself. The same considerations apply to the international

situation, where the degree of institutional weakness, the ability of the vulnerable to right back, and absence of a collective morality is even more pronounced. Writers that have been concerned with this weakness have argued that the only solution is to develop the decision-making capacity of vulnerable groups. This has led to programs of community development, rural development, and capacity building. At national levels, it might ask for a broad based program, involving the government as well as non-government and private sector institutions (see Banuri et al 1994).

This still leaves open the question, however, whether there is an ethical framework that can enable national societies, and indeed the global human society, to response to the emerging problems in an equitable manner.

VI.4 The Question of Ethics

Equity, justice, fairplay are all concepts with strong moral and ethical overtones. The above literature exhibits these overtones either explicitly or implicitly. It is fair to say, however, that the policy-oriented literature seeks an ethically neutral stance. It is based on a technocratic approach, which focuses on the means or instruments to given or agreed goals. In this approach, the only ethical considerations pertain to the goals, but not to the means through which the goals are to be achieved. The goal of this literature is to determine a universal formula for decision making. Differences between philosophers pertains not to this search for a universal formula, but to the contents of the formula.

This distinction is not simply that between outcomes and processed. For example, Nozick (1977), argues for liberty as the primary principle not only in its own right, but as the definitive feature of equity. This is generally taken to be an example of process oriented ethics. However, it too is consequentialist, in that it assumes a transcendental goal, which can be achieved through the appropriate institutions--in this case free markets. Similarly, Rawls (1971) analyzes the concept of justice from an individualistic viewpoint to argue for a Solomonic veil of ignorance which would induce each individual to seek a maxi-min solution. If this could be agreed, presumably we could also agree to establish institutions (a government, a judiciary) that will put our values into action.

Both these perspectives, two of the most salient recent analyses of the issue of justice, derive from a 'consequentialist' position, in which values have to be justified by outcomes--even if they are defended by processes. Hannah Arendt (1961) has made a scathing critique of such approaches, by arguing that they are based on a confusion between meanings and values as well as between values and goals. The result is that everything is reduced in the end to means. In this approach, culture and values become mere instruments for the achievement of particular goals (e.g. development). Indeed, even equity is but an instrument for the pursuit of such goals as economic growth or political stability.

This, however, is not the only possibility. An alternative approach, which would be sensitive to Arendt's criticism, sees culture and values (including equity) as foundational, and as developed through experience. This is implicit in Rawls, when he says that 'the primary

subject of justice is the basic structure of society' (Rawls 1971: 7). Following this, Michael Sandel (1982) has commented that 'a just society must have justice as a constitutive of its framework, not simply an attribute of certain of the participants' plans of life. This is the definition of a moral community, and not a society of strangers.

Arendt herself has argued against transcendental principles, by invoking judgment as an alternative entry point--contextual, subjective, interactive, and constructive of community. Judgment requires being able to judge particulars without subsuming them under general rules. Such concepts as justice, courage, truth, goodness, are not based on general rules, but on concrete experiences. If one takes this point of view, the search for universal rules is dangerous as well as futile. Justice lies in experience, not in transcendental rules. Equity and efficiency do not collide as contrasting goals. We cannot have equity in an inequitable society.

However, this perspective presupposes an alternative institutional structure, in which the experience of value creation can become possible again. This structure must build upon small, decentralized communities, in which the scope for judgment is re-established. As such, this would go against the broad trends of twentieth century development. This has been in the direction of greater centralization and concentration. It has also been accompanied by the transfer of all collective rights to the state. In the realm of economics, therefore, it has left an amoral universe, in which equity can only be an instrument towards the achievement of some other goal, not a value in its own right.

VII Procedural fairness in international climate change processes

VII.1 Introduction

The various differences between countries outlined in this chapter have implications for the way in which international responses to climate change are developed--in the context of the different equity issues discussed in the introduction, issues of procedural equity are important as well as the consequences of decisions taken, indeed the two ultimately are likely to be inseparable. Oran Young (1990) notes that:

"One of the most robust findings of the social sciences is that .. [countries in international negotiations] .. can and often do fail to realize feasible joint gains, thus ending up with outcomes that are suboptimal (and sometimes highly destructive) for all concerned."

Part of the reason is the lack of trust and inadequate information that can arise from negotiations that are, or are perceived as, operating in an unfair or inequitable way. The result can be--and often is--that countries do not even agree things that would benefit each and every one of them. Hence the importance of procedural equity.

One important element of procedural equity has been mentioned in section II: namely, the principle of sovereignty in international affairs, coupled with a responsibility towards the impact of internal actions upon others. The difficulty with climate change of course is that it is an issue in which the activities of every country have impacts on all others; hence the need for processes through which states can seek agreement on mutual changes to reduce such impacts, and/or to compensate accordingly.

These principles apply to the negotiations, associated processes like the IPCC, and any institutional structures and procedures created through negotiations. The principle of seeking consensus among all participating states for international agreements makes it still more important that participants feel that negotiations are conducted fairly and that they feel able to participate effectively; and that states take part in good faith. Countries that do not perceive a process to be fair have great power to obstruct it, ensuring that negotiations make little progress.

Procedural equity is an aspect of institutions and the construction of international institutions is partly about establishing structures that command widespread adherence as containing adequately fair representation; the painstaking negotiations over the Global Environmental Facility can be seen largely as negotiation about fair representation.

The overall literature on institutions is very large, and there is considerable literature (especially in the US) about institutions for managing global environmental affairs (e.g. *Millenium* 1990; WRI, 1992; Young 1991; Choucri, 1994). The academic literature specifically on practical aspects of equity in international institutions for managing global

environmental affairs is however much smaller; among the most important is the report of the IPCC Special Committee on the Participation of Developing Countries (IPCC, 1990).

The main issues in procedural equity include:

- adequate participation (and associated resources);
- adequate information (and associated resources);

Here "resources" is used in the broad sense of the word; it encompasses human resources, financial resources, institutions and infrastructure that can underlie adequate participation in and information for effective negotiations.

These issues are important. The cost of inadequate participation is likely to be low adherence to any resulting agreement. The cost of inadequate information is likely to be a suspicious and obstructive attitude which reduces negotiations to a crawl. We consider each in turn.

VII.2 Participation

Participation in international processes--at the simple level of having nationals or other representatives present--is limited chiefly by limitations in human and financial resources, though delays in obtaining visas and the sheer difficulty of travel from some developing countries can also be important constraints. For some processes (like the IPCC), financial constraints upon travel from poorer countries are addressed through special funds supported by developed countries, though inevitably there are recurring concerns about their adequacy. The matter of human resources is more difficult to deal with, since it depends partly upon long-run education and reflects the contrary priorities in many developing countries outlined in section III.1.

A related problem can be the appropriateness of participants and the load upon them. Many of the smaller and/or poorer developing countries had just a few delegates covering the whole range of UNCED negotiations, compared with several hundred for example from the US. They could not possibly have the specialized knowledge required to participate effectively.

That said, it is obviously unrealistic to expect universal participation in everything, indeed it would be a huge waste of scarce human and financial resources, and would in a sense be unfair to participants with more urgent priorities. In practice, the smaller countries--in both the industrialized and developing world--are selective about their participation through choice as well as need, without necessarily adverse consequences. Smaller countries may be able to rely upon larger neighbors that share common interests, or otherwise be able to ensure that their concerns are reflected through delegated or grouped responsibilities. Luxembourg for example generally has little difficulty signing on to agreements in which it played no direct

part. And as noted earlier, addressing climate change requires widespread but not necessarily universal participation. Where universal participation is impractical or even undesirable, what matters is ensuring that a fair balance of interests and perceptions are represented.

A related problem is that of institutional coordination within countries. Climate change involves an extraordinary diversity of issues and interests, ranging from meteorology to international trade. Frequently governments have trouble coordinating policy between different internal groups--and in the international arena it is indeed not uncommon for meteorologists from developing countries to find themselves discussing issues which are more to do with international trade policy.

Concerns about the ability to participate effectively underlie the frequent insistence of many developing countries on Rules of Procedure, such as the development of official negotiating timetables without intercessional meetings. To bigger and more advanced countries this can be an intense irritation and may seem an unnecessary brake on program (which such procedures may indeed turn out to be). To weaker and poorer participants they are seen as a protective device to give them a chance to keep up with discussions. Again, it is an area where a fair compromise between adequate progress and comprehensive participation is called for.

VII.3 Information

Perhaps a bigger problem than adequate participation is adequate information for those who participate. Climate Change issues are complex. The work of the IPCC spans complex issues ranging from atmospheric science to ecology to economics. OECD representatives in particular can draw upon a huge infrastructure of specialist knowledge and analysis in developing policy positions and arguing for them (even if researchers still feel that insufficient attention is paid to their work, and negotiators feel deluged by research of which much is peripheral or naive). Many developing countries feel seriously disadvantaged by not having adequate research capacity to draw upon; it is striking for example that the Indian Minister of Finance expressed such a concern (on a different issue) despite India having one of the most developed policy research capabilities in the developing world (in Ghosh *et al.*, 1993).

Again this reflects a mix of problems: a lack of human and financial resources, limited education infrastructure, and weak communications. The IPCC Special Committee recommended a number of steps that could be taken, including the support for regional centers and seminars and the development of regional specialists to help improve information and analytic capabilities in developing countries, particularly as it affects the ability of these countries to get to grips with the climate change issue.

The importance of adequate information cannot be overstressed. Many bad policy decisions can be traced to inadequate information, and so can many of the difficulties in international negotiations. The feeling that some participants are much better informed than others can, and frequently does, lead to a suspicious and obstructive attitude in negotiations which ultimately may be to the detriment of all. It was noted above that in international affairs, countries often do fail even to reach agreements that would be of mutual benefit. Lack

of adequate information and the distrust this can help to generate is one root cause of this. Negotiations are difficult enough when each country is seeking only to pursue a narrowly-defined self interest. They can be even worse when they do not have a clear idea of where their self-interest lies.

VII.4 Links between internal and international processes

The focus in this discussion has been upon state actors and government representatives. But fair representation in international discussions also requires that those attending fairly represent interests within their own countries, and their effective participation also requires them also to draw upon the human and other resources of the non-governmental sector. There is thus increasing acceptance that non-governmental organizations have an important role to play in the process: in harnessing and analyzing information; in developing international links; in assessing the implications of proposed policies; in changing cultural attitudes, including communication across different sectors of society; and in observing and monitoring implementation of decisions agreed internationally (for example Haas *et al.*, 1993; Brenton, 1994; Choucri 1994).

A number of these elements have been discussed in the section VI above. Given the complexity of the climate change issue, this points to the ultimate inseparability of issues such as fair and informed participation between the national and international levels. Addressing climate change--both adaptation and abatement--may require changes at many different levels of society, and the implementation and acceptance of policy at many different levels.

Thus, we come full circle to the observation at the beginning of this chapter. Perceived justice, in terms of representation and consideration of different perspectives in processes and in big decisions, is one of the basic measures of legitimacy for governmental institutions. Equivalent structures internationally are weak or non-existent. But the climate issue forces recognition of global interdependence. For negotiations to be effective, they need to command widespread acceptance as fair processes, reaching decisions that reflect fair compromises between widely divergent views of what constitutes an equitable outcome, and thus reflecting the range of issues addressed in this chapter.

VIII Conclusions

Equity and social considerations are central to discussions of steps to be taken to implement Framework Convention on Climate Change because widespread participation is essential if the objectives of the Convention are to be gained. This is why the concept of equity is so prominent in the Convention. Countries are unlikely to participate fully unless they perceive the arrangements to be equitable. This applies particularly to equity among regions and countries, but equity within countries, and associated social considerations, are also important influences upon what is possible and desirable. Mitigating and adapting to climate change will require actions on the part of individuals. Governments will find it easier to comply with international obligations if their citizens feel that the obligations and benefits of compliance are distributed among them equitably. And richer countries are unlikely to burden their poorer citizens to benefit relatively rich citizens in poor countries.

Scientific analyses cannot prescribe how social issues should be taken into consideration and how equity should be applied in implementing the Climate Convention, but analysis can clarify the implications of alternative choices and their ethical basis. There are a variety of meanings of equity and there are various principles that have been designed to achieve equity. On some issues different equity principles point to similar responses, suggesting clear guidance, while on others they may conflict. In either case, there is a need for judgment, drawing on concepts of equity.

Issues relating to equity among regions and countries stem from the substantial differences that exist among countries. Countries differ not only in terms of size, resources, population, and wealth, but also in terms of emissions of greenhouse gases, vulnerabilities to climate change, and institutional capabilities to respond effectively to climate change. There is no single method of aggregating these differences, or decision rule for dealing with them. The Framework Convention on Climate Change provides considerable guidance for applying the concept of equity so as to take account of the many differences among countries. However, the application of equity to specific circumstances will require further elaboration of the Convention's principles and obligations, many of which were designed to be ambiguous and remain so.

Equity issues involved in responding to climate change may be divided into four distinct categories:

- distributing the costs of adaptation;
- distributing future emissions rights;
- distributing the costs of abatement; and,
- ensuring institutional and procedural fairness.

The Framework Convention on Climate Change offers some guidance on all of these issues. It requires developed country Parties to take the lead in limiting their emissions whilst

recognizing that developing countries' emissions are relatively low and will need to grow to meet their legitimate social and developmental needs. It also requires developed country Parties to assist developing country Parties to cope with both the costs of abatement as well as the costs of adaptation to the adverse effects of climate change. Such assistance must be provided by the Convention's financial mechanism which must have "an equitable and balanced representation" and transparent governance to ensure procedural equity between donor and recipient country Parties.

This North-South focus is also apparent in much of literature, which seeks to clarify issues of equity between developed and developing countries much more than among developed countries. Since developed countries have obligations under the treaty to take immediate action, this is a serious lacunae. There are however a variety of specific analyses that propose schemes for distributing costs of coping and abatement and emission rights, and analyze the distributional effects of these schemes, across the range of countries.

Social considerations, and the experience of the implementation of structural adjustment policies, point to the need to consider and target for special consideration specific groups. Countries (such as island and other low-lying states, or drylands) and special groups within society (such as the poor, and sometimes women or children, or specific occupations or regions) that are especially vulnerable to climate change--those on whom the costs of abatement and coping would be especially burdensome--merit special attention.

Concern about equity and social impacts points to the need to strengthen institutional capacities, particularly in developing countries, to make and implement collective decisions in a legitimate and equitable manner. These institutional capacities surely include developing resources to analyze equity and social issues.

Institutional weaknesses also inhibit the ability of developing countries to participate effectively in international negotiations. Assistance to help these countries develop a greater capacity to assimilate and analyze information and proposals, and to participate effectively in international discussions, would increase the prospects for achieving effective, lasting and equitable agreements on how best to address the threat of climate change.

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Notes

¹ Four main types are identified. A 'heirarchical' view believes that a problem like climate change needs to be managed rationally and that this can be achieved by suitable management institutions backed by good science and judgement. A 'market' view believes that the problem should be characterised primarily as an economic externality, and that the solution lies in creating property rights and a market structure which enables market actors to internalise these costs in their transactions. An 'egalitarian collective' view places the emphasis upon equal rights in limited and perhaps fragile biosphere, emphasising the need for radical abatement and abstinence from excessive consumption. A 'fatalist' view considers that humans can adapt to whatever changes are caused and probably cannot manage abatement effectively anyway, thus arguing for no action.

² On equity generally, Tom Franck and Dennis Sughue, "Equity as Fairness," 81 *Geo L.J.* 563 (1993); Dan Tarlock, "Environmental Protection: The Potential Misfit Between Equity and Efficiency," 63 *U. Colo.L.Rev.* 871 (1992); Edith Brown Weiss, "International Environmental Law: Contemporary Issues and the Emergence of a New World Order," 81 *Geo L.J.* 675 (1993); Cheng "Equity, Special Considerations and the Third World" 1 *Colielp* 57 (1990); See also, Oscar Schachter, *Sharing the Worlds Resources*, Columbia University Press (1977) and Philippe Sands, *Principles of International Environmental Law*, Manchester University Press (forthcoming).

³ U.N. Doc. A/CONF.151/5/Rev.1 (1992), reprinted in 31 *I.L.M.* 876.

⁴ *Case Concerning the Continental Shelf (Tunisia/Libyan Arab Jamahiriya)*, 24 February 1982, *I.C.J. Rep.* 1982.

⁵ *Id.* p.60 para. 71.

⁶ *Id.*

⁷ See generally Bin Cheng, *General Principles of Law as applied by International Courts and Tribunals*, Cambridge, Grotius Publications Ltd, (1987).

⁸ *I.C.J. Rep.* 1982, p.59, para.70.

⁹ *Id.*

¹⁰ *Case Concerning the Continental Shelf (Libyan Arab Jamahiriya/Malta)*, *I.C.J. Rep.* 1985, p.30, para.46.

¹¹ *Id.*

¹² *Case Concerning the Continental Shelf (Libyan Arab Jamahiriya/Malta)*, I.C.J. Rep. 1985, p.30, para. 46.

¹³ *Id.*

¹⁴ *Id.*

¹⁵ *Id.* p.33, para 50.

¹⁶ *Jan Mayen case*, I.C.J. Rep. 1993, p.29, para. 57.

¹⁷ *Gulf of Maine case*, I.C.J. Rep. 1984, pp.97-102, paras. 230-241.

¹⁸ See, Tom Franck and Dennis Sughrue, "Equity as Fairness," 81 *Geo L.J.* 563 (1993); Dan Tarlock, "Environmental Protection: The Potential Misfit Between Equity and Efficiency," 63 *U. Colo.L.Rev.* 871 (1992).

¹⁹ On the legal status of the common heritage principle see Patricia Birnie & Alan Boyle, *International Law and The Environment*, Clarendon Press, Oxford (1992) pp. 120-22.

²⁰ See Richard Benedick, *Ozone Diplomacy: New Directions in Safeguarding the Planet*, Harvard University Press (1991) and Gunther Handl, "International Efforts to Protect the Global Atmosphere: A Case of Too Little, Too Late?" 1 *EJIL* 250 (1990).

²¹ See Daniel Bodansky "The United Nations Framework Convention on Climate Change" 18 *Yale J.Int'l L.* 451 (1993), at. pp. 493-96.

²² Article 31, 1969 Vienna Convention on the Law of Treaties (Vienna Convention).

²³ Annex I lists the European Community and 35 states, the 24 members of OECD in 1992 (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States of America) and 11 European states that are undergoing the process of transition to market economies (Belarus, Bulgaria, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Russian Federation, and Ukraine).

²⁴ Smith and Ahuja (1990) present succinct and strong reasons for considering the range of gases in assessing individual projects, together with a general framework indicating a basis on which such comparisons might be developed. At the aggregate level required for international comparisons and considerations of equity the issues are somewhat different. The best data, and most analysis, has focused upon the major contribution from CO₂--especially from fossil fuels, for which national emissions are generally known to within ± 5 percent (uncertainty range of 10 percent) or better. CFC emissions--measured as defined in the Montreal Protocol--are known to similar accuracy. Other sources are more uncertain. National estimates of CO₂ and

other emissions from deforestation and other land use changes can vary by at least ± 30 percent, both for individual countries and even in aggregate; most methane emissions are similarly uncertain. Contributions from other gases (N₂O, and various other gases involved in different aspects of atmospheric chemistry) are still more uncertain, but the global impact of these other emissions probably totals less than 10 percent of the major greenhouse gases. Further difficulties are introduced in attempting to compare the radiative impact of different gases, as discussed in earlier IPCC reports. Ahuja (1990) present succinct and strong reasons for considering the range of gases in assessing individual projects, together with a general framework indicating a basis on which such comparisons might be developed. At the aggregate level required for international comparisons and considerations of equity the issues are somewhat different. The best data, and most analysis, has focused upon the major contribution from CO₂--especially from fossil fuels, for which national emissions are generally known to within ± 5 percent (uncertainty range of 10 percent) or better. CFC emissions--measured as defined in the Montreal Protocol--are known to similar accuracy. Other sources are more uncertain. National estimates of CO₂ and other emissions from deforestation and other land use changes can vary by at least ± 30 percent, both for individual countries and even in aggregate; most methane emissions are similarly uncertain. Contributions from other gases (N₂O, and various other gases involved in different aspects of atmospheric chemistry) are still more uncertain, but the global impact of these other emissions probably totals less than 10 percent of the major greenhouse gases. Further difficulties are introduced in attempting to compare the radiative impact of different gases, as discussed in earlier IPCC reports.

²⁵ This would apply, for example, if one considered the impact of a single country's emissions in the absence of any other emissions, or evaluated the marginal impact of adding each country's emissions in turn, with all the others fixed. None of the literature appears to attempt such an assessment explicitly, and scientific understanding of the carbon cycle may not be sufficient to perform such calculations with confidence.

²⁶ To a degree there are parallels here with the debate over the allocation of sinks (see box). Looking only at total emissions is similar to the WRI index; focusing upon per-capita emissions gives a very different view more closely related to that of Agarwal and Narain. Considering national per-capita emissions relative to the global per-capita mean (so that they can be negative as well as positive), as advanced by Mukherjee (1992), is directly equivalent to the approach advocated by Agarwal and Narain.

²⁷ Action by one group of countries to limit fossil fuel emissions, for example, will tend to depress international fuel prices which may accelerate emissions growth elsewhere if other regions do not participate. Conversely, it is likely to accelerate technology developments which may then diffuse, acting in the opposite direction. The net effect is difficult to predict and depends upon timescales and models of elasticities and technology development and diffusion [as discussed elsewhere in this report?].

²⁸ Wilford cites an insurance study, that irrespective of any equity considerations: 'it may become necessary for the government to assume a share in catastrophe covers, at least for losses exceeding a certain level, or to guarantee indemnification in all events, as some governments already do in the case of the risk of flood and inundation' (Rückversicherungs-Gesellschaft, 1990, p.11).

²⁹ The correct criteria should include a cost component known as the quasi option value, reflecting the expected value of the losses in options following the irreversible change.

³⁰ The Coastal Zone Management subgroup of the IPCC Response Strategies Working group suggests a slightly different division of 'retreat', 'accommodation', and 'protection' in response to sea-level rise. The classification given here reflects the different kinds of costs incurred, that may require different instruments.

³¹ A detailed discussion of Rawlsian criteria applied to CO2 abatement is given in Benestad (1993).

³² Footnote on the difficulties of defining comparable burdens, etc.?

³³ 'If the remaining global fossil carbon budget were shared according to strict person-year equity including historic emissions, industrialised countries would have not emission rights left. A reasonable compromise between international equity and practical feasibility would be allocate 150BtC each to industrialised and developing countries' (Krause et al, 1990, Executive Summary).

³⁴ Davod A. Wirth and Daniel A. Lashof, *Ambio*, Vol.19 October 1990 pp305-310: to be checked.

³⁵ Note that this does not imply equal benefits over time, as technology development and other factors enable more value to be extracted from a given level emissions. The issue has some elements in common with issues of natural resource depletion and the intergenerational equity issues discussed in the previous section but the literature has not explored this in any depth.

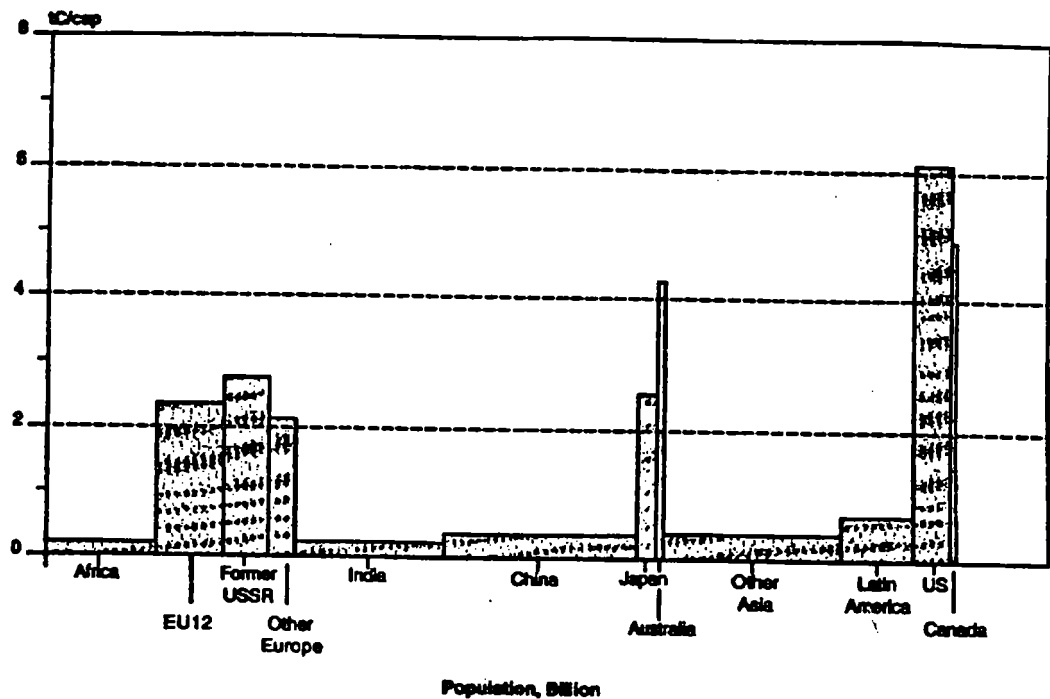
³⁶ As one relevant indication, the peak energy intensities achieved by countries in the process of industrialisation has steadily declined over the century, as those developing later can draw upon better technologies developed elsewhere (Haeefe, 11981).

³⁷ Ghosh (1993) agrees in theory that positive as well as negative externalities associated with development transfer from one country to another, but points out that any such application of the principle 'must be comprehensive .. all external contributions of all persons over all time must be accounted for .. allowing for those developing countries which were the cradle of civilisation to claim resource transfers .. it is difficult to devise practical ways of implementing this principle.'

³⁸ Clarify p. 79

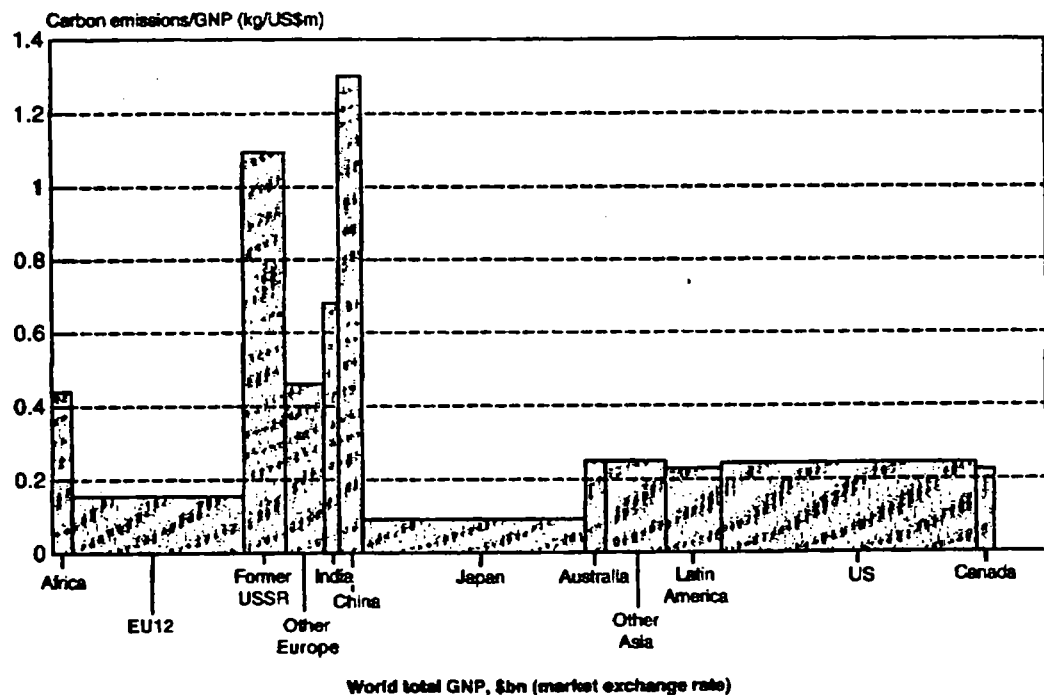
³⁹ It specifies directly how a country's effort should vary as a function of its own income level and abatement efficiency; if the welfare weights are equal across countries, then it defines directly the optimal relative contribution from each country.

Figure 1
Carbon Emissions per Capita and Population, 1993



Source: Derived by M. Grubb from BP Statistical Review of World Energy 1994 and World Population Prospects, UN

Figure 2
Carbon Emissions/GNP and Total GNP, 1992



Source: Chapter 3

Chapter 5

**APPLICABILITY OF TECHNIQUES OF
COST-BENEFIT ANALYSIS
TO CLIMATE CHANGE**

Prepared for
**WORKING GROUP III
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE**

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TABLE OF CONTENTS

1 Introduction	1
2 Cost-Benefit Analysis	2
3 Unique features of Global Warming	6
4 Cost-Benefit Analysis in the context of Global Warming	10
Estimates of the Marginal Cost Curve	11
The marginal benefits curve	13
Measuring costs and benefits	15
The joint products problem	17
The aggregation problem	18
Systemic evaluation	20
5 Issues	21
Risk, Uncertainty, and Irreversibility	21
Valuation	27
The Discount Rate	32
CBA and Equity	33
Multi-criteria analysis (MCA)	35
6 Concluding Remarks	40
7 Bibliography	42

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Summary

Cost-benefit analysis has many advocates but also many detractors. Certainly the rather narrowly defined, traditional approaches to CBA, developed originally for project level decision-making with planning horizons typically no more than 20 years, clearly have difficulty in dealing with the very long time frames, and high levels of uncertainty, encountered in the climate change. However, a family of techniques used in decision analysis, that are associated with a more broadly defined CBA approach provides a more promising basis for analyzing climate change issues.

In the introduction we noted that there were four essential questions facing decision-makers regarding climate change: (1) by how much should emissions of GHGs be reduced?; (2) when should emissions be reduced; (3) by what method should emissions be reduced?; and (4) who should reduce emissions?

The first question is answerable by CBA provided costs and benefits could be estimated with adequate accuracy -- the measures whose marginal costs are less than the marginal damage costs should be implemented. Clearly, it matters what perspective is taken: the result will be different if restricted to a consideration of national costs and benefits than if the perspective is global. It is a fundamental result of CBA that the global perspective is the proper one.

The second question is a more complicated one, because it involves judgments about uncertainty. If the marginal damage (benefit) cost were known with certainty, or if future technological advances that might significantly change the marginal cost curve were known with certainty, then the timing of abatement is given by that portfolio of implementation options that maximizes the (deterministic) present value of avoided damage costs (benefits) less abatement costs -- a relatively straight forward calculation.

But since neither damages nor costs are known with certainty (for example, if fusion technology were to be commercially available at a cost comparable to fossil-fueled technology by 2020 then the optimal timing and structure of abatement actions looks very different than if the date were 2070), extensions of CBA -- such as decision analysis -- are required. As indicated in Section 4 (see e.g. Box 2), recent developments have begun to deal with the question of timing, particularly with respect to the balance between R&D (on both the cost and benefit side) vis-a-vis immediate commitments to emission abatements.

The third question is closely related to the first. As we have seen (for example in Figure 4.2), most attempts to answer question 1 necessarily require consideration of the specific methods that might be used to reduce emissions. A bottom-up, empirical estimation of the marginal cost curve involves analysis of the broad spectrum of possible abatement options, from which marginal cost curves can be derived. Top-down models, typically using national or regional general equilibrium models (recall the results of Figure 4.4), also necessarily require explicit consideration of specific policy or technology options.

CBA cannot itself resolve the fourth question -- which involves equity -- but it does provide a framework for understanding the trade-offs to be made between equity and economic efficiency. CBA, when applied globally, can identify in which countries abatement costs are lowest, since the global perspective identifies all measures whose marginal costs are less than the global marginal benefits (recall Figures 4.5 and 4.6). But how such a program can be implemented in practice involves putting in place appropriate transfer payment mechanisms, the amount and structure of which is a matter of equity.

Nevertheless, despite its many imperfections, CBA (broadly defined) remains the best guide to policy-making for dealing with the essential questions that must be faced in dealing climate change. The CBA approach forces decision makers to compare the consequences of alternative actions, including that of no action, on a quantitative basis -- and can certainly make a contribution to resolution of the first three of these questions. To the extent that some impacts and measures cannot be valued monetarily (like biodiversity), extensions of the traditional CBA approach, such as multi-criteria analysis, permit

quantitative expression of the trade-offs to be made.

Finally, one should emphasize that the most important benefit of applying CBA is not necessarily the predicted outcome (which is always dependent upon assumptions and the particular technique that is used), but the *process itself*, which forces an approach to decision-making that is based on rigorous and quantitative reasoning.

1. Introduction

In public policy-making, a comparison between the perceived costs and the perceived benefits of an action is routinely made by decision-makers. However, this choice is frequently made on intuitive and qualitative grounds. Cost benefit analysis (CBA) provides an analytical framework that seeks to compare the consequences of alternative policy actions on a quantitative rather than qualitative basis. Indeed, the approach forces quantitative thinking, for its very essence is that costs and benefits must be expressed in a common monetary unit that provides the basis for the tradeoffs. The basic principles are well understood and straight forward: for an action to be justified, the costs of the action should be less than the benefits derived therefrom¹. If there are several alternatives, then one ought to pick that option whose benefits most exceed the costs.²

The objective of this Chapter is to examine how and under what circumstances can CBA make a contribution to the resolution of the central questions now facing decision-makers about global climate change: (1) by *how much* should emissions of greenhouse gases (GHGs) be reduced? (2) *when* should emissions be reduced? (3) *how* should emissions be reduced? and (4) *who* should reduce emissions? CBA can at least theoretically and conceptually answer the first three questions. The fourth question is one of equity, and not amenable to resolution by CBA even in simple, traditional applications not complicated by the complexities of the climate change problem³.

Section 2 defines more carefully what is meant by CBA: in fact the term has come to encompass a wide variety of specific techniques. We also review the basic concepts. In section 3 we examine the unique features of global warming and climate change as they pertain to decision-making. Section 4 presents a discussion of the application of CBA to the climate change problem in light of these unique features. In section 5 we discuss the key issues: risk uncertainty, irreversibility, valuation, discounting, equity, and multiple criteria.

Indeed, that cost-benefit analysis is appropriate to the analysis of policy options to address global climate change is not universally accepted. A major report recently issued by the US Office of Technology Assessment (OTA, 1993) contains an extensive discussion of how adaptation strategies should be chosen, yet manages to avoid all mention of cost-benefit analysis *per se*. It talks about how one might minimize vulnerability to climate change and about insurance strategies, but avoids the central question of how one might determine the amount of insurance one wishes to buy. Similarly, priorities may be set on non-economic grounds, and CBA could be used in a secondary role (see e.g. Turner, 1991).

Although this needs a little bit of modification in the presence of capital constraints, which may limit selection of the "best" single project.

However, as we shall see later, extensions of CBA can help in identifying the trade-offs between economic efficiency and equity.

2. Cost-benefit analysis

Cost-benefit analysis (CBA) is a generic term that subsumes a wide body of specific techniques developed initially as a means to evaluate projects that were limited in scale, geographic extent, and time span, the original techniques have been extended to cover applications of increasing complexity. Traditional project level CBA (see Box 1) is too narrow to be relevant for evaluating climate change issues. However, CBA more widely defined, includes a family of approaches that are useful in this context. For example, cost-effectiveness analysis has been widely used for climate change analysis.

However, in order to evaluate cost effectiveness, it is crucial to clarify how the target is defined, because there are several options in the global climate change context. Most of the recent analyses of the mitigation costs have focused on a target based on future emission levels,⁴ such as stabilization of the emission of certain greenhouse gases by a given year. However, it might be more relevant to express the targets in terms of concentrations of atmospheric greenhouse gases at some future time.

To change the target for climate policy from emissions to atmospheric concentrations indicates a radically different cost effectiveness strategy. A stabilization of CO₂ emissions at present levels is not sufficient to stabilize the atmospheric concentrations. Richels and Edmonds (1993) have compared the costs of reaching some particular concentration level by year 2100 from alternative strategies. They show that a given concentration level in year 2100 could be achieved at a considerably lower cost path than by stabilizing emissions immediately. The reason is that a more gradual reduction of emissions would avoid the economic shock following a sudden stabilization of emissions, future advanced technologies could be utilized to a larger extent, and sizable abatement costs postponed.

A third possible target, also affecting the cost effectiveness of alternative measures, could refer to the physical consequences of climate change. Apart from the fact that predictions of these consequences are far more difficult to make than forecasts of emissions and atmospheric concentrations of greenhouse gases, the effects of regional differences would have to be included if targets were based on the consequences. For instance, whether climate change contributes to sea level rise or to an increase in the frequency of rain storms will be of quite different importance to people in Nepal and Netherlands. In this context, an additional problem arises as to how to assess benefits from abatement of different consequences for different countries.

A further refinement of CBA is multi-criteria analysis (MCA), a body of techniques developed to deal with the difficulties of economically valuing certain types of impacts (see Box 1). Indeed, even if one attempted to place economic value on certain impacts -- such as human life -- not everyone agrees that it is *appropriate*. Moreover, cost-benefit analysis presupposes that costs and benefits are those perceived by humans -- an endangered species might view the trade-off between threatened habitat and GHG emissions in an entirely different way, and use a different numeraire than money⁵.

The degree of emission abatement is reported in such studies in two rather different ways. The first is as a reduction from some baseline -- itself defined as the trajectory of GHG emissions for some postulated business-as-usual scenario. The second is in terms of reductions from some reference year (e.g. "reduce greenhouse emissions to 80% of their 1990 levels, by 2010").

A recent survey of economists and scientists knowledgeable about the climate change problem elicited typical views at the extreme of this spectrum (W. Nordhaus, Expert Opinion on Climatic Change, *American Scientist*, 82, 45-51, 1994). One respondent argued "the existence value of species is irrelevant -- I don't care about ants except for drugs", while another cautioned that "loss of

Box 1: Techniques of cost-benefit analysis (CBA)

Traditional project level CBA

CBA evolved as a technique to evaluate and compare project alternatives. In the early years of its application, there was little concern with externalities, and the analysis took into account just the direct costs of projects, and the direct benefits. Developed in the industrialized world, market prices provided appropriate guidance on how to evaluate benefits. When the World Bank began to apply the technique to non-market economies, where prices were subject to significant distortions, shadow pricing techniques provided simple corrections. For example, if an oil-importing country kept the domestic price of oil at artificially low levels, CBA requires the use of the border price, not the domestic price, as a basis for valuing oil.

One of the central concepts in CBA is that of discounting, which addresses the fact that costs and benefits may not occur at the same point in time. For example, while costly actions to avoid future climate change may need to be taken in the near future, most of the benefits of such actions will occur far in the future. Discounting enables one to take into account the time value of money. In the case of evaluating simple investment alternatives over shorter time horizons (e.g., < 15 years), the use of the opportunity cost of capital as the discount rate to be applied to both costs and benefits, is well established and uncontroversial. However, in the case of complex public policy applications, particularly those whose time horizons are very great, and involving environmental impacts or the depletion of natural resources – essential characteristics of the global climate change issue – there is sharp disagreement as to what discount rate is appropriate. This issue is dealt with in Section 5.

Cost effectiveness analysis

As CBA began to be applied to much broader contexts, and particularly to the comparison of alternative portfolios of projects and to broad policy choices, the increasing complexity made it desirable to keep the level of benefits constant, and to analyze the problem simply in terms of finding the most effective, or "least-cost" option to meet the desired level of benefits. This has the additional advantage that benefits in some cases do not need to be explicitly valued. For example, in power sector planning, models are applied to identify the capacity expansion plan whose present value of system costs are minimized, given some exogenously specified time path of electricity demand, and some exogenously specified level of reliability. As we shall see below, this is the variant of CBA that has seen the most widespread application to the climate change problem, in which one seeks to identify the least-cost option to achieve given levels of GHG emission reductions, without any explicit attempt to specify what the benefits of that level of emission reduction may be.

Multi-criteria analysis

The most basic requirement for the application of CBA is that both costs and benefits can be given economic value. This is typically a two step process: first the costs and benefits must be quantified in terms of the physical measures that apply; and then those physical impacts must be valued in economic terms. Some applications of valuation techniques are likely to be controversial. Putting a value on human health and illness has been a major problem in the practical application of cost-benefit analysis in the past, even in those situations where one can agree upon the levels of increased morbidity and mortality that might be caused by some policy or project. Efforts to place economic value on the loss of biodiversity have been equally difficult. Recognizing this problem has led to the development of so-called multicriteria analysis (MCA) techniques, which are expressly designed to deal with multiple objectives – of which economic efficiency may be only one of several. MCA is a particularly powerful tool to quantify and display the trade-offs that must be made between conflicting objectives.

Decision analysis

While MCA addresses certain shortcomings of conventional CBA (like valuation problems), it does not necessarily deal more effectively with uncertainty. This complication has led to the development of a further extension of CBA that goes under the general term decision analysis. Here the focus is expressly on how one makes decisions under conditions of uncertainty. These techniques find application in a wide variety of situations, from decision-making in the high risk field of wildcat oil drilling to analysis of financial options. As we shall see below, such techniques provide a rational approach to deal with irreversibility, one of the more important characteristics of the climate change problem.

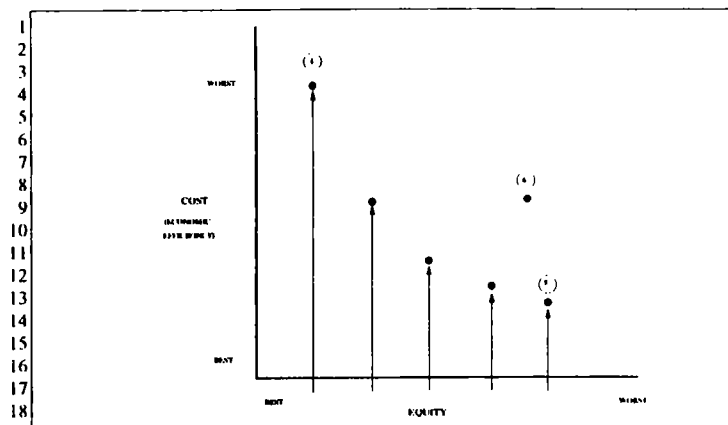


Figure 2.1: Multi-criteria analysis

Such views give further support for MCA-based approaches to decision-making. Similarly, there are concerns that monetized values themselves may be inaccurately estimated, and in any case such values might not reflect welfare. However, the question of who is affected, and how they will perceive the impact, is an issue that needs careful definition in an MCA analysis.

As noted earlier, conventional CBA cannot provide answers about the optimum level of equity in the same way that it provides answers about the optimum level of economic efficiency. But MCA can identify the trade-offs between equity objectives and economic efficiency, as suggested by Figure 2.1. Thus, the best equity result (indicated by option 1, say an equal per capita sharing of the burden of GHG emission reduction) may have the highest cost; while the worst equity result (indicated by option 5, say based on the present distribution of GHG emissions), may have the lowest economic cost. Nevertheless, even MCA requires a quantification or at least an ordinal ranking of the non economic efficiency criteria, as suggested in the figure. However, even such a non-cardinal ranking may prove problematic when a global issue like climate change requires comparisons across countries and cultures.

More generally, it is increasingly accepted that the pursuit of sustainable development will require recognition of goals related to economic efficiency, social equity, and environmental protection (Munasinghe, 1993). Economic valuation of the impacts of climate change on certain social and environmental aspects (e.g. biodiversity or cultural assets) will be difficult, and MCA related approaches will be needed to make the trade-offs among otherwise non-compensable costs and benefits.

genetic potential might lower the income of the tropical regions substantially". In Section 5 we address the different types of value – use, option, existence – in more detail.

But see below for a discussion of the difficulties of making cross-country comparisons of costs.

There may also be some outcomes that are inefficient, i.e. those that lie inside the frontier of efficient points shown on Figure 2.1. Such an inefficient point is represented by option 6. This is discussed further in the presentation of multi-criteria analysis, below.

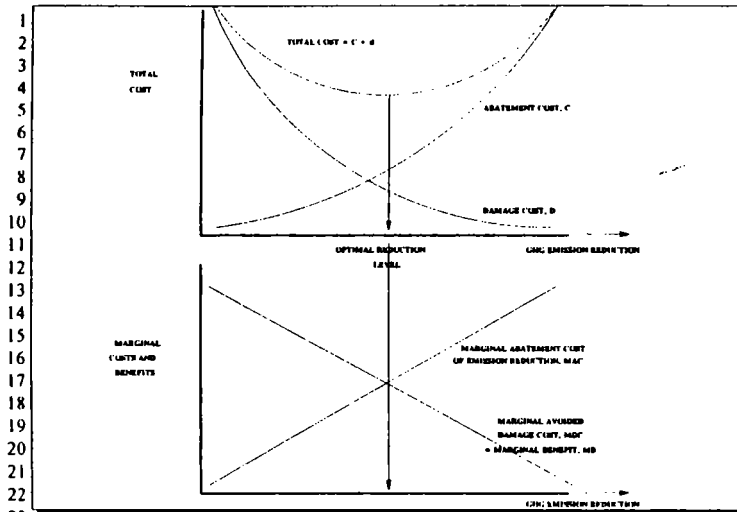


Figure 2.2: Total and marginal costs and emissions reductions.

Basic concepts

An economically efficient policy for emissions reduction is one that maximizes the net benefits, i.e. maximizes the benefits of reduced climate change less the associated costs of emissions reductions⁴. Economic theory provides that emission reduction efforts should be pursued up to the level where the marginal environmental benefits of an additional unit of reduced warming is equal to the marginal cost of emissions reduction. Figure 2.2 illustrates the concepts of total and marginal costs in simplified form -- the marginal costs at any level of emission reduction is equal to the slope of the total cost curve at the same level.

The shape of the total cost and benefit curves reflects the idea of diminishing returns. Each additional unit of emissions reduction will have a higher unit cost. The first 10% reduction can be done cheaply, but the next 10% will cost considerably more, and so on.⁵ Thus the

It should be noted that the algebra of cost-benefit analysis can be expressed in many different ways: the cost-benefit ratio, net present value, or the internal rate of return are all different ways of doing the arithmetic. However, particularly in situations involving portfolios of potential actions, and where shortages of capital may constrain the choice, great care must be paid to rigorous application of principles; else different methods can yield different decisions. Maximizing net present value subject to applicable resource constraints is the most useful approach for climate change analysis.

Perhaps the simplest and most intuitive example as to why the marginal cost of emissions reduction increases with increasing levels of reduction is the removal of pollutants from wastewater. The first 60% can be easily removed by a settling basin, that require just a structure. Large particles simply settle by gravity. The next 30%, to reach, say 90% removal, requires biological treatment, this requires not just a physical structure, but pumps to aerate the water to promote aerobic bacteria. The

1 abatement cost curve is upward sloping (with increasing slope) as shown on Figure 2.2A.
2 Similarly, the marginal benefit (or avoided cost of GHG damages) falls as emission levels are
3 reduced. The consequences of the foregoing is that the total cost (TC) has a minimum at the
4 point where the slope of the abatement cost curve equals the negative slope of the damage cost
5 curve (or avoided costs).¹⁰

6 The foregoing analysis ignores many complications. For example, the emission of a unit
7 of CO₂ may give rise to a varying stream of environmental costs which must be discounted to
8 yield a present value aggregate. The environmental damage function may be discontinuous and
9 non-convex. Abatement costs may change over time, depending on when the technologies are
10 applied -- because of technological progress. Similarly, abatement costs may exhibit economies
11 of scale (e.g. mass production of solar photovoltaic cells), resulting in a marginal cost curve
12 that actually declines beyond a certain point. Finally, the abatement costs are net costs, to the
13 extent that certain technologies (e.g. renewables) may produce other (non-climate related)
14 benefits and costs -- the so-called joint products complication (discussed below).

16 3. Unique features of climate change

17 There are several important characteristics that define the conventional context in which CBA is
18 applied. First is that costs and benefits arise within a time span typically no more than 15-25
19 years, corresponding roughly to the physical life of most projects over which benefits are
20 derived. Second is that the elements of uncertainty are relatively tractable, and can often be
21 characterized by probability distributions.

22 Most of these characteristics are very different in the context of climate change. The
23 relevant time spans extend to a century or more. The uncertainties are extremely large, and few
24 elements of uncertainty are amenable to characterization as probability distributions. Moreover,

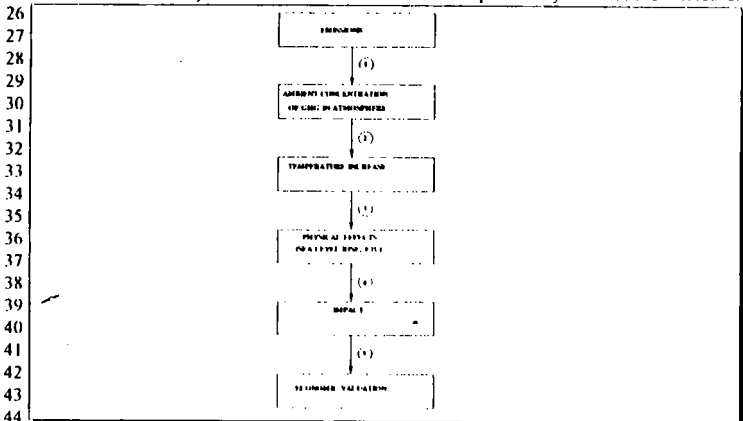


Figure 3.1: The chain of causality

47 next 5-6% requires chemical treatment, with high operating costs of chemical agents. 100% removal,
48 theoretically possible, would require complete distillation, which is extremely expensive.

1 the cascaded uncertainty implied in each link of the chain of causality greatly amplifies the total
2 uncertainty in the final outcome, namely the extent of damage caused by climate change.

3 Figure 3.1 shows the chain of causality. It begins with emissions of greenhouse gases.
4 While the most important of these is CO₂, it should be noted that there are many other gases
5 that contribute to the climate change phenomenon, including methane, and CFCs. While
6 estimates of CO₂ emissions from fossil fuel combustion are fairly straight forward, emissions
7 from other sources are subject to much higher uncertainty. Moreover, the separation of
8 anthropogenic and natural causes of climate change is much more difficult than in the case of
9 other important regional/global pollution issues (such as CFC's or nuclear wastes). Indeed, the
10 calculus of CBA may be significantly affected by natural events such as major volcanic
11 eruptions.

12 The first link (1) is between emissions and the resultant ambient concentration of CO₂ in
13 the atmosphere. Unlike other pollutants that are subject to complex chemical transformations
14 in the atmosphere,¹¹ the calculation of the ambient concentration increase that follows from a
15 given increment of emissions of CO₂ is relatively simple. However, because of the role of
16 natural sources and sinks (particularly the ocean), even this calculation is subject to a
17 considerable degree of complexity and uncertainty.¹²

18 The next link (2), between atmospheric concentration and temperature, is subject to much
19 greater scientific uncertainty. The greenhouse effect itself, i.e. the trapping of incoming solar
20 radiation, is subject to all kinds of additional factors that are highly complex. For example, if
21 temperatures rise, and cloud cover increases, feedback effects involving increased reflection of
22 incoming radiation will complicate the calculation of equilibrium temperatures.

23 The next link (#3) involves many different components, all of which are to some degree
24 difficult to calculate. For example, calculating the rise in sea level associated with increases in
25 mean sea temperature proves to be far from simple in some cases (as noted in IPCC WGI in the
26 case of the West Antarctic ice sheet). Even more complicated are estimates of how
27 precipitation patterns might change, especially the spatial and temporal distribution of rainfall.
28 Perhaps of even greater concern in the developing countries will be the changes in the patterns
29 of extreme weather events, to which they are particularly vulnerable.

30 If these physical effects are understood in general terms, quantifying the impacts on the
31 flora and fauna is much more difficult (link #4). Suppose it were possible to predict the
32 change in precipitation and temperature regime for some given region. What can be said about
33 the shifts in vegetation patterns? While general poleward shifts of vegetation and agricultural
34 production zones can be predicted in general terms, quantifying the effect is quite difficult.
35 What is the impact on biodiversity? On wetlands? On the water table? Clearly these are very
36 difficult assessments to make.

37

38
39 ¹¹ Although we show the marginal cost and benefits as linear in emissions reduction in Figure 2,
40 this need not be so. For example, where abatement costs are subject to economies of scale, there might
41 be sections of the MC curve that have a form other than that shown on Figure 2.2. But as noted
42 elsewhere (e.g. Figure 4.1 for the U.K.), empirical studies of the marginal cost curves frequently do
43 exhibit the stylized shapes shown on Figure 2.

44 ¹² The acidity of precipitation is influenced by complex interactions between sulfur oxides,
45 related oxidation products, and NO_x.

46 For example, the presence of CFCs could affect climate change not only directly through its
47 greenhouse warming potential, but also indirectly by its impact on biota like nanoplankton -- which in
48 turn influence oceanic CO₂ uptake. Similarly, the degree of reliance on fossil fuels would affect CO₂
49 directly, and CO₂ absorption indirectly -- via the effects of acid rain on forests and biomass.

1 Finally, in order to estimate the damage costs, one needs to be able to value these effects
2 (link #5). Some valuation tasks will be relatively straight forward: for example, the cost of
3 engineering structures to protect against sea level rise are relatively easy to establish, given the
4 existing experience in this field (in such countries as the Netherlands). Other calculations will
5 be more complex, but at least tractable: as for example, the calculation of increased cooling and
6 decreased heating costs on the energy system, or the impact of increased irrigation pumping
7 requirements associated with drier climates in some regions upon electricity demand. But a
8 very large number of potentially important impacts are very difficult to value such as the
9 impacts on forests, wetlands, and biodiversity.

10

11 *Special features*

12

13 Beyond the degree of uncertainty, what makes the analysis of the climate change problem so
14 different to other environmental analysis problems? The main reasons can be summarized as
15 follows:

16

17 GHGs are stock, not flow pollutants:

18 Many pollution phenomena are relatively short-lived, such that the damages are closely related
19 to the current rate of emissions. This is because the rate at which most pollutants are removed
20 from the atmosphere is relatively rapid (say in the case of particulates by dry or wet
21 deposition). Reducing emissions at major sources will likely have a relatively immediate
22 impact. In the case of GHGs, however, the damages occur as a result of the total atmospheric
23 concentrations at any one time, in other words, are related to the stock of the pollutant, not to
24 the current rate of emissions.¹³

25 Therefore, in the context of the climate problem, the global climate is a lagged function of
26 the various greenhouse gases. At any point of time, these atmospheric concentrations (which
27 are stock concepts) depend on the whole time path of emission of the greenhouse gases up till
28 the point of time under consideration. Similarly, an increase in current emissions of a
29 greenhouse gas at any point of time will affect the atmospheric concentrations of this gas, and
30 thus the climate, in all future periods.

31 To calculate the marginal environmental cost of increased current emissions of a
32 greenhouse gas, one must first calculate the physical impact of such an emission increase on the
33 future development of the atmospheric concentration of the gas. This will depend on physical
34 characteristic of the gas, which affect how rapidly an increased atmospheric concentration
35 depreciates. There are large differences between different greenhouse gases, with atmospheric
36 lifetimes varying from some 15 years for methane¹⁴ to more than 100 years for CO₂, N₂O and
37 some CFCs.

38 Once the impact of current emissions of a greenhouse gas on future atmospheric
39 concentrations has been calculated, one can in principle calculate the effect of the increase in
40 current emissions on the future climate development. If one has specified a function which
41 measures the monetary cost of climate change, one may thus calculate the incremental costs,
42 and thus obtain a present value measure of the marginal cost of increased current emissions of a
43 greenhouse gas.

44

45 ¹³ There are of course some exceptions, notably for radioactive wastes, which also have an
46 extremely long life, thus the total environmental risk, and the scale of the disposal problem at any one
47 time, is not so much dependent on current rates of production of nuclear wastes, as on the total stock.

48 ¹⁴ The IPCC Special report, 1994, estimates the lifetime of methane at 14.5±2.5 years

1 It is clear from the description above that the marginal monetary cost of greenhouse gas
 2 emissions is a complex concept. Several assumptions of an economic nature must be made,
 3 such as the appropriate discount rate and the monetary costs of climate change for the whole
 4 future. In particular, the relative importance of different greenhouse gases is much more
 5 complex than some simple physical conversion into a common index. In the context of the
 6 climate problem, a reasonable definition of the importance of a greenhouse gas relative to, say,
 7 CO₂, is the marginal environmental cost of current emissions of this gas relative to the
 8 corresponding marginal cost of CO₂. It follows from the discussion above that the relative
 9 importance of GHGs depends on a number of economic assumptions which must be made.¹⁵

10

11 Inertia and irreversibility:

12 Since the emissions of GHGs in any one year represent a relatively small fraction of the total
 13 global stock, the system has great inertia. This means that even if all emissions went to zero, it
 14 would be decades, if not centuries, before the stock of GHGs become reduced significantly.
 15 Therefore, in effect, decisions about emissions reduction become effectively irreversible, at least
 16 over the 100-200 year timespan of interest. In other words, failure to reduce emissions in the
 17 short to medium term may be irreversible in the sense that once the effects of climate change
 18 become apparent, it will then be too late to do anything about it.

19

20 Global characteristics:

21 Most environmental pollution problems are local or regional in scale.¹⁶ The benefits of
 22 emissions reductions generally accrue to the same geographic areas as would otherwise bear the
 23 costs. The damage associated with GHGs, however, are dependent upon the total global GHG
 24 concentration, largely independent of the regional meteorological patterns that usually define
 25 the geographic scope of other trans-national environmental problems such as acid rain.
 26 Therefore the distribution of benefits of emissions reduction is global, not local. Per contra,
 27 even a country that emits no GHGs would incur the damages of emissions by other countries.

28

29 Geographical distribution of impacts:

30 Poorer nations are likely to be the most vulnerable to the impacts of climate change, since they
 31 lack the resources to protect themselves against sea level rise, extreme weather events, or
 32 desertification. For example, the impacts of acid rain tend to be concentrated in richer
 33 countries, from emissions in poorer countries or regions (Japan from China¹⁷, Richer West
 34 Germany from E. Europe).¹⁸ These richer areas therefore have powerful incentives to promote

35 ¹⁵ See e.g. Hoel and Isaksen (1993, 1994) for a further discussion and numerical calculations.

36 ¹⁶ There are exceptions here as well, most notably the phenomenon of acid rain, which is largely
 37 a long-range phenomenon often involving emissions in one country, and acid rain damage in another.
 38 However, to the extent that lake acidification completely destroys aquatic ecosystems, one could argue
 39 that at least some of the impacts are irreversible, although even here the impacts are generally of a
 40 fairly local nature. Long time periods may also elapse between the onset of acid rainfall, and to actual
 41 visible damage.

42 ¹⁷ For new data on emissions and acid deposition rates in Asia, see *Interim Report*,
 43 *International Collaborative Project on Acid Rain and Emissions Reduction in Asia*, World Bank, Asia
 44 Technical Department, September 1993.

45 ¹⁸ To be sure, there are exceptions. For example, to some extent, even the richer countries of
 46 Europe among themselves are affected by mutual pollution problems (e.g. acid rain in Scandinavia
 47 from the U.K., or the severe water pollution problems in the Rhine Basin involving Switzerland,
 48 Germany France and Holland, or the dumping of wastes in the North Sea). However, in most of these
 cases of international pollution issues involving richer countries, much better institutional mechanisms

1 emissions reductions programs in the source areas, including the provision of financial
 2 assistance.¹⁹ By contrast, in the case of GHG emissions reductions, countries such as the U.S.
 3 (where there is the *perception* that the *direct* impacts of climate change on the U.S. itself are
 4 relatively small), may have less obvious economic motivation to reduce emissions.²⁰
 5 Considerations of humanitarian solidarity and equity alone will unlikely be sufficient.

6

7 Absence of actual impact data:

8 Unlike almost all other environmental externalities, in the case of climate change it might be
 9 argued that there are few directly relevant actual data, and that predictions of physical impacts
 10 are based entirely upon the predictions, judgments, and models of scientists.²¹ Only once (or
 11 if) climate change does in fact occur, will the impacts be known. The evidence of
 12 cause-and-effect will be difficult to substantiate, because of the likelihood that, at least initially,
 13 changes will be incremental. It should be noted, however, that there does exist a significant
 14 body of verifiable scientific theory that underlies the estimates and models of scientists.

15

16 Non-linearity:

17 Global climate change is determined by complicated interactions involving a chain of non-linear
 18 linkages (i.e. GHG emissions - atmospheric concentration - temperature change - physical
 19 impact). Therefore, climate change phenomena and risks are likely to be much more non-linear
 20 than the relationship between conventional emissions and more local pollution.

21

22 Very long time frame

23 The very long time frames involved in climate change make some of the normally exogenous
 24 variables endogenous. For example, the economic impact of sea-level rise is dependent upon
 25 the size of the population living in low-lying coastal areas, which may decrease once a sea level
 26 rise becomes evident. The costs of such adaptation mechanisms may be especially difficult to
 27 estimate.

28

29

30 **4. Cost-Benefit Analysis in the context of climate change**

31

32 In light of these unique characteristics of the climate change problem, what can we say about
 33 the suitability of CBA? How and under what circumstances can CBA make a contribution to
 34 the central questions now facing decision-makers: (1) by *how much* should emissions be
 35 reduced? (2) *when* should emissions be reduced? and (3) *how* should emissions be reduced?

36

37 exist for addressing their problems (e.g. the EU in Europe) than are available for resolving
 38 environmental disputes between rich and poor.

39

40 ¹⁹ For a discussion of the relationship between economic assistance for restructuring in Eastern
 41 Europe and assistance to guarantee desired environmental standards, see e.g. M. Amman *et al.*,
 42 *Economic Restructuring in Eastern Europe and Acid Rain Abatement Strategies*, *Energy Policy*,
 43 p. 1187-1198, Dec. 1992.

44

45 ²⁰ However, the indirect impacts, for example large scale immigration from Mexico that might
 46 follow from agricultural devastation in that country, may ultimately prove to be much more serious for
 47 the U.S. than the direct consequences of sea level rise or higher energy bills for air conditioning, but
 48 such impacts are also very difficult to quantify, and many regard them as speculative. Proper CBA
 analysis, to be sure, would correct for such distorted perspectives

47

48 ²¹ In some cases laboratory experiments -- such as growing plants in CO₂-enriched atmospheres
 -- do of course provide some actual data for predictions

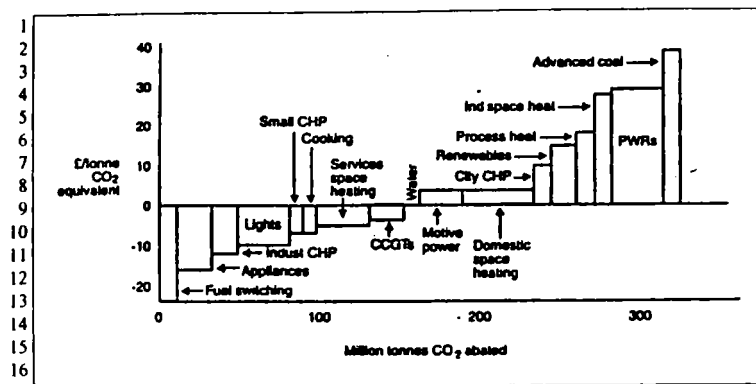


Figure 4.1: The marginal cost curve for the U.K.

The fundamental problem in applying CBA to the climate change problem flows directly from the chain of causality discussed above: while estimating the costs of emissions reduction involves the beginning of the chain, estimating the benefits (or the avoided damage costs) involves the very end of the chain. Since there is some level of uncertainty associated with each of the links, estimates at the last stage of the chain are subject to compound uncertainties which may be very large indeed.

Estimates of the marginal cost curve

Marginal abatement cost (MAC) curves got GHG emission reductions have been derived for many industrialized countries, but for only few developing countries.²¹ On Figure 4.1 we show the cost for the U.K., as estimated by Jackson (1991). The curve is derived by a rank ordering of the individual measures considered by cost per ton of CO₂ saved (the height of each block), with the width of each block representing the tons of CO₂ so saved. The shape of the MAC curve, when smoothed, is indeed of the type indicated on Figure 2.2, a result confirmed by many other examples.²² Generally, these studies rely on known or near-term technical options, and ignore effects due to joint products, economies of scale, and capacity building, that might reduce the upward slope of the cost curve. A more detailed discussion of estimates of the MAC curves is contained in Chapters 8 and 9.

What is interesting in these (and other studies²³) is the significance of "below the line" options (i.e. MAC is negative but still upward sloping). These are measures that appear to

²¹ A recent UNEP review on GHG abatement costing studies concluded "...the state of abatement costing studies in developing countries is wholly inadequate even to draw preliminary conclusions concerning possible costs and the impact of different abatement options. It is a body of analysis which is only just beginning, and which may take many years to mature towards consensus even on very rough estimates and understanding of the key issues (UNEP, *op.cit.*, p. 66).

²² See e.g. the review of eleven studies by London Economics (1992).

²³ See e.g. J. Moreira *et al.*, 1992 for Brazil; S. Sitnicki *et al.*, Opportunities for Carbon Emissions Control in Poland, *Energy Policy*, 19, 10, p 995-1002, 1992, or P. Meier, M. Munasinghe and T. Siyambalapitita, *Energy Sector Policy and the Environment*, World Bank Environment

I have negative costs associated with them -- in other words, when these options are implemented, both costs and emissions go down, relative to the reference case.²⁴ Compact fluorescent lighting, other energy efficient devices, and demand side management measures typically fall into this category, and in developing countries, measures such as reducing T&D losses, or instituting vehicle maintenance programs, also appear here. These, then, are measures that should be implemented in a least cost energy development strategy, even in the absence of any desire to reduce GHG emissions. The fact that they are not implemented reflects either market failures, the influence of powerful vested interests, or other factors, such as high transaction cost (which might exceed the potential benefits)²⁵. Indeed, in developing countries, there may be more such "below the line" options because education and information about the availability and benefits of options in this segment of the MC curve is worse than in developed countries.

This issue highlights a practical problem for the Global Environment Facility (GEF). The GEF has been set up as the funding mechanism, on an interim basis, to provide financial resources needed by developing countries to meet the "full incremental costs incurred" in complying with their obligations under the Convention on Global Climate Change.²⁷ If the GEF is to fund the "incremental costs" of GHG reduction measures, this presupposes that a baseline can be unambiguously defined, against which such incremental costs are to be measured.²⁸ But

²⁰ Department, 1993, (for Sri Lanka).

²¹ Unfortunately there is some confusion in terminology here. Some (e.g. London Economics, *Economic Costs of Carbon Dioxide Reduction Strategies*, Global Environment Facility Working Paper Series 3, Washington, DC, 1992), use the term "no regrets" to describe policies for which MB > MAC, i.e. for which the marginal benefits exceed the marginal costs. Others use the term only where MAC < 0, i.e. to those options that are "below the line" in the empirical cost curves of the type shown on Figure 4.2. However, since on both the cost and the benefit side there will be some netting out (e.g., to account for joint costs and benefits), the criterion MAC < 0 is arbitrary, whereas MAC < MB is well defined.

²² The fact that such "no-regrets options" are in fact observed is much debated. What may be calculated as monetary benefits need not necessarily be regarded as benefits to decision-makers -- there may be other, non-monetary costs involved. The huge subsidies given to European agriculture illustrate the point that more than monetary benefits might be involved. In the case of developing countries, the unavailability of finance may constrain the ability to implement some of these options. For example, until recently, obtaining finance through export credits for power generation expansion has been much easier than financing energy efficiency measures.

²³ These methodological problems have been recognized by GEF, who has initiated a research program to find an operational approach for measuring and agreeing upon full incremental costs within the context of the Climate Change Convention, the so-called PRINCE study (Program for Measuring Incremental Costs for the Environment). See K. King, *Issues to be Addressed by the Program for Measuring Incremental Costs for the Environment*, Global Environment Facility, Working Paper 8, Washington, DC 1993.

²⁴ Moreover, another problem here is that the concept of "least cost" as well as the integrated planning process to achieve it, may be quite complex (see e.g. M. Munasinghe, *Energy Analysis and Policy*, Butterworths Press, London, UK, 1990, P. Meier, Power Sector Innovation in Developing Countries: Implementing Investment Planning under Capital and Environmental Constraints, *Annual Review of Energy*, 15, pp 277-306, 1990, or E. Crousillat, *Incorporating Risk and Uncertainty in Power Sector Planning*, Industry and Energy Department Working Paper, Energy Series Paper 17, World Bank, Washington, DC, 1989). Such a solution, typically obtained by fairly sophisticated optimization models, may be "least cost" only for a very narrow band of input assumptions, and if these assumptions prove to be different, then an investment program predicated upon the "least cost" plan may ultimately be distinctly non-optimal.

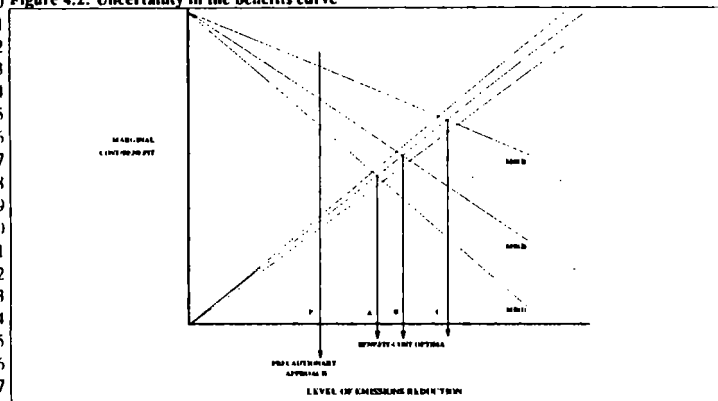
under such a definition, should demand side management programs which have negative incremental costs-- such as energy efficient lighting -- be funded by GEF?²⁹

4 The marginal benefits curve

It follows from the discussion of the previous section that the level of uncertainty in benefits is much greater than the level of uncertainty in the cost curve. The practical implication of this, depicted in Figure 4.2, is that the optimum point of emissions reduction is also subject to significant uncertainty (indicated by points A, B, and C): whether the marginal benefits curve is MB1, or MB2 or MB3 has a much greater impact on the location of the optimum point of emissions reduction than the much smaller uncertainties in the marginal cost curve. Therefore, with such wide uncertainty about the economic optimum, CBA may not be very helpful. On the other hand, a "precautionary" level of emissions reduction, at P, has a very high probability of at least meeting the criterion that MB>MC.

In fact, there exist few if any estimates of the benefits curve, and most of the estimates that do exist are not much more than single point estimates for some presumed level of GHGs in the atmosphere. Table 4.1 shows some estimates of the GDP impacts of climate change (whose avoidance represents the benefits of abatement). A complete discussion of benefits estimates is provided in Chapter 6.

Figure 4.2: Uncertainty in the benefits curve



In the words of King, *op.cit.*, "...How can the adoption of apparent win-win solutions be stimulated? Such solutions are sometimes referred to as negative incremental cost projects because they are economically viable in their own right. The dilemma arises because these projects are often not being funded. On the one hand, if the GEF restricts itself to those projects that have positive incremental cost while the bulk of negative incremental cost options remains unfunded, it risks becoming irrelevant to the main solution to the global environmental problem. On the other hand, providing grant finance for economically viable projects effectively makes a net transfer to the country, which is not the purpose of new and additional funding; worse, it provides a perverse incentive to potential recipient countries to delay economic reform (p.17)"

Table 4.1: Estimates of the impact of climate change (billions of 1988 dollars)

	U.S.			Global		
	Nordhaus	Cline	Fankhauser	Other	Fankhauser	Other
Heavily affected sectors						
agriculture	1	15.2	7.4	1.2	39.1	12.3
coastal areas	10.7	2.5	2.3			
energy	0.5	9				
other sectors						
wetlands and species loss		7.1	14.8			
health and amenities		8.4	30.3			
other	38.1	11.2	12.1			
total	50.3	53.4	66.9			
total as % of output (GDP)	1	1.1	1.3		1.5	2.8(a)

Blanks denote not available. (a) from Nordhaus's survey of experts. Sources: Nordhaus(1991), Cline(1992), Fankhauser (1992); for agriculture under "other" Reilly and Hohmann, 1993. Source: Nordhaus (1994), p. 69.

A number of estimates for the industrialized countries (especially the well-known work of Nordhaus for the U.S.) suggest that the economic impact of climate change on the industrialized countries is quite small. However, Nordhaus, as well as others, are quick to concede that such results may not apply to developing countries, where typically much larger shares of national income are in agriculture, and much of it in subsistence farming in marginal areas where even small changes in climate may have devastating effects, and where the ability of the farming population to adapt may be very small indeed.³⁰ The types of human settlement most vulnerable to climate change are concentrated in developing countries, including low-income communities, residents of coastal lowlands and tropical islands (such as coastal Bangladesh, or the Maldives), populations in areas already significantly affected by desertification, and the urban poor in squatter settlements³¹

This is likely to be true even though higher CO₂ concentration itself may promote plant growth.

For further discussion, see e.g. J. T. Houghton *et al.* (Eds) *Climate change--The IPCC Scientific Assessment*, World Meteorological Organization and the United Nations Environment Program, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 1990; or L. B. Lave and K. Vickland, *Adjusting to Greenhouse effects: the Demise of Traditional Cultures and the Cost to the USA*, *Risk Analysis*, 9, 283-291, 1989. However, as also noted by Nordhaus (1994), the fertilizing effect of atmospheric CO₂ is a particularly strong mitigating factor for Agricultural nations, particularly where water is a limiting factor: while the extent and quantitative importance of CO₂ as a fertilization agent are controversial, the balance of the evidence is positive (Nordhaus, 1994, p. 369)

Unfortunately, to date, most of the discussions of impacts of climate change on the developing countries have been qualitative in nature,³² and there is an urgent need for more quantitative estimates for developing countries. According to a recent GEF survey of country studies³³, there are now almost as many studies underway on effects as on mitigation, but it is difficult to ascertain how many of these studies, most of them now underway, will result in the sort of quantitative information necessary to construct an impact cost curve. Certainly none of the studies and papers published to date for developing countries contain quantitative estimates of the type derived by Nordhaus for the US.³⁴

Measuring costs and benefits

Most of the work on the benefit (avoided cost) side, and much of the work on the cost side, assumes that the relevant measure by which to evaluate options is loss of GDP. This raises a separate set of questions about the extent to which GDP, (or loss of GDP growth) is the appropriate measure.³⁵ It is well established (Weitzman, 1976; Brekke, 1994) that GDP is not a welfare measure per se, but rather a convenient way to aggregate goods and services which clearly contribute to welfare. Nevertheless, Figure 4.3 summarizes some of the estimates that have been made for GDP impacts; Chapter 9 discusses such estimates in more detail.

Thus it is well recognized that GDP is an imperfect proxy for social welfare. One recent Norwegian study (Alfsen, Brendemoen and Glomsrod, 1992) showed significant differences in cost-effectiveness of different policy options for GHG emissions reduction policy when consumer surplus effects were also included in the analysis.³⁶ These effects have found to be significant in developing countries as well, as shown by Meier *et al.* (1993) in the case of Sri Lanka (see Table 4.2).

³² see e.g. the discussions of P. Glick, *Climate Change and International Policies: Problems Facing Developing Countries*, *Ambio*, 18, 6, p 333-339, 1989; or R. K. Pachauri, *Global Warming: Impacts and Implications for South Asia*, Tata Energy Research Institute, New Delhi, 1991).

³³ J. Fuglestad *et al.*, *A Review of Country Case Studies on Climate Change*, Global Environment Facility, Working Paper 7, Washington, DC, 1994. This report identifies 39 studies (or elements of studies) focused on inventories of GHGs, 48 studies of effects, and 46 studies on mitigation.

³⁴ For example, in a report prepared by the Tata Energy Research Institute for the India Ministry of Environment and Forests, the Chapter on Adaptive Strategies for India in the Perspective of Climate Change, which elaborated the impacts associated with given levels of sea level rise and mean temperature, was entirely qualitative in nature, and no cost estimates were attempted. (TERI, *Report on Global Warming and Associated Impacts*, Report to the Ministry of Environment and Forests, January 1991). Similarly, neither Volume on Climate Change published by the Asian Energy Institute (Pachauri and Behl, (Eds), 1991), nor the country studies conducted by UNEP (Reported in UNEP, 1992) contain any country specific estimate of costs associated with specific levels of GHG accumulation in the atmosphere. ADB is currently sponsoring a multi-country project in Asia that is attempting to establish costs of potential effects.

³⁵ There are several related issues. For example, should one use nominal exchange rate, trade-weighted rates, or purchasing power parity rates in making cross-country comparisons of costs or impacts?

³⁶ Consumer surplus impacts have been vigorously debated in the United States in terms of how to evaluate the costs and benefits of demand side management (DSM) programs. For example, Hobbs (1991) shows that some programs may have positive benefits under a simple "least cost" criterion from the utility perspective (avoided supply costs exceed program costs to the utility), but have negative benefits when changes in consumer surplus are taken into account.

Table 4.2: Impact of welfare losses of GHG abatement options in Sri Lanka
(in \$/ton of avoided carbon)

	no coal	wind	CFL
supply cost impact	16	67	-472
consumer impact	10	66	-66
total	26	131	-538

source: Meier, Munasinghe, and Siyambalapitiya, *op. cit.*, 1993.

notes: negative numbers indicate a benefit
CFL= compact fluorescent lighting

Of course, the magnitude of such impacts is a function of how much of the technology is adopted, how soon, and what discount rate is used. The effect of a single 25Mw wind plant will obviously be much less than if a 300 Mw wind farm displaces an imported coal plant in the near-term. Generally, what these results do underscore is the need for great caution when interpreting the so-called costs of GHG-emission reductions attributable to specific technologies.

Equally important are the concerns over the extent to which conventional measurements of GDP growth take into account the depletion of natural resources ("Green Accounting"). For many developing countries this is a particularly important issue, and there is a growing literature suggesting that conventional accounting substantially overstates GDP growth. The corollary is that estimates of GDP impacts of climate change that fail to take into account changes in the rate at which natural resources are depleted, or in environmental impacts, may be understating the true effect.³⁷

Some of these problems are evident from the numerical estimates. On Figure 4.3 we display the results of recent studies of the impact of emissions reduction strategies on loss of

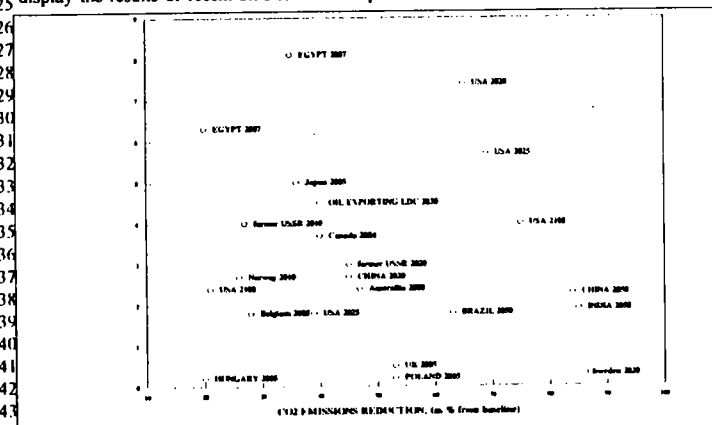


Figure 4.3: Impact of GHG emissions reductions on GDP

The question of "green accounting" is one of valuing and aggregating marketable and non-marketable goods (see e.g., United Nations (1993), or Munasinghe *et al.*, 1995). The many

1 GDP¹⁰. As is evident, these impact estimates show considerable variation, even so, none of
 2 these estimates reflect "green accounting", and only one takes into account joint products.¹¹
 3 Most of these studies are national studies. Many researchers argue that unilateral action by the
 4 US or by OECD countries are likely to be less effective than global action, and that unilateral
 5 actions are likely to exaggerate the impact on GDP.¹² However, these studies also neglect the
 6 benefits of the development of advanced technologies in the market economies, which could then
 7 be more quickly adapted in the developing world

8 Traditional CBA basically relies on a partial equilibrium framework which takes a large
 9 number of parameters, including prices, as given. For questions relating to climate change,
 10 (whose consequences may have major effects on prices), the more far-reaching and inclusive
 11 general equilibrium approach is appropriate. For this reason, computable general equilibrium
 12 models are widely used in climate change studies.

13 The joint products problem

14 A related question concerns the joint benefits and costs of emissions reduction. Options that
 15 reduce GHG emissions may also provide significant changes in other pollutants whose impacts
 16 are of a quite different scale. For example, the substitution of renewable energy technologies
 17 for coal will reduce not just CO₂ emissions -- a global benefit -- but also SO₂ and particulate
 18 emissions that bring a reduction in local environmental damages. On the other hand, the
 19 increased use of renewable energy technologies (such as hydroelectric generation), which also
 20 reduce CO₂ emissions, may also impose new and different local environmental costs (such as
 21 loss of biodiversity associated with reservoir inundation).¹³

22 Estimates of the importance of joint benefits and costs vary widely (in part because
 23 valuing the costs and benefits of other environmental impacts may be subject to similar
 24 difficulties of valuation and scientific uncertainty as for GHG emissions), but most lie in the
 25 range of 1 to 10\$ of additional benefits for every dollar of benefit from GHG emission
 26 reduction.¹⁴ A recent Norwegian study (Alfsen, Brendemoen and Glomsrod, 1992) indicated
 27 different proposals for "green accounting" reflect the difficulties involved. Rather than speculate
 28 about valuation, or poorly founded proxies for non-marketable goods, MCA provides an alternative
 29 approach

30 These results are for studies that estimate both emissions reductions and GDP impacts relative
 31 to some baseline, i.e., relative to the trajectory of emissions in the absence of the policies followed. For
 32 many countries, particularly the developing nations, even significant reductions from such baselines
 33 may still imply increases in the absolute quantity of GHGs emitted. Other studies report results in
 34 terms of GHG emissions in some future target year, relative to emissions in some prior year (e.g. 2010
 35 emissions 10% less than 1990 emissions).

36 S. Glomsrod, H. Vennemo, and T. Johnson, *Stabilization of Emissions of CO₂: a Computable
 37 General Equilibrium Assessment*, Central Bureau of Statistics, Discussion Paper 48, Oslo, Norway,
 38 1990.

39 For further discussion see UNEP, *op.cit.*, p.72. Studies that have examined the question of
 40 unilateral v. multilateral approaches include Proost and van Regemorter (1990) for Belgium, and
 41 Edmonds and Reilly (1983) and Rutherford (1992).

42 Additionally one might note that, while the environmental risks of current technologies are
 43 fairly well established, those that apply to new technologies -- including some that are sometimes
 44 proposed as solutions to the climate change problem (such as fusion, or new nuclear reactor cycles) --
 45 are less certain

46 For example, if we use the externality values suggested by the California Energy Commission
 47 (\$26/ton for CO₂, 14,483 \$/ton for NO_x, \$7,425\$/ton for SO₂, and \$57,620\$/ton for TSP), then
 48 estimated benefit of reducing electricity demand by 1 mwh is 23\$ for CO₂, and 74\$ for the reduction

1 that when the joint products of carbon reduction were taken into account (reduction in
 2 environmental damages to forests and lakes, health damages, reduced traffic congestion, road
 3 damage etc.), then such benefits go a long way toward compensating the economic loss
 4 measured as reduction in GDP.¹⁵

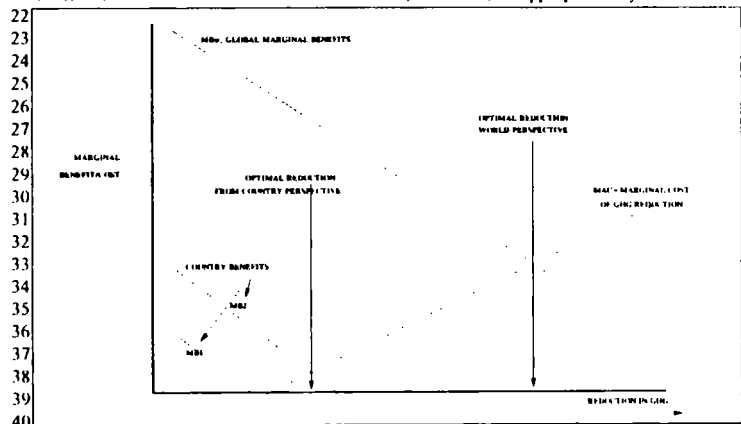
5 Adding the benefits of reductions in conjoint pollutants to the MB measure is one
 6 possibility. The other is to subtract these benefits from the MC measure. Since most of such
 7 benefits go to the country that bears the costs of abating the CO₂ emissions, while the benefits
 8 of less CO₂ emissions go to all countries, it follows that the preferred approach is to adjust the
 9 marginal cost curves.

10

11 The aggregation problem

12 We now turn to the matter of implementing policy. Consider first Figure 4.4, which depicts the
 13 situation faced by some country. Its marginal cost curve is upward sloping, in the manner
 14 discussed above; it begins with negative values (the "no regrets" or "win-win" options) again in
 15 the manner indicated earlier.

16 Suppose Figure 4.4 depicts the situation for an industrialized country, say the US.
 17 Suppose that indeed Nordhaus is correct in his estimates that the benefits to the US are rather
 18 small. If MB₁ were true, then the optimal policy would be only to implement the win-win
 19 policies -- demand side management, more efficient end-use devices, economically efficient
 20 pricing, and the like. If MB₂ were true, for the US perspective, then perhaps only small
 21 emissions reductions are warranted. We assume, of course, an appropriate adjustment for the



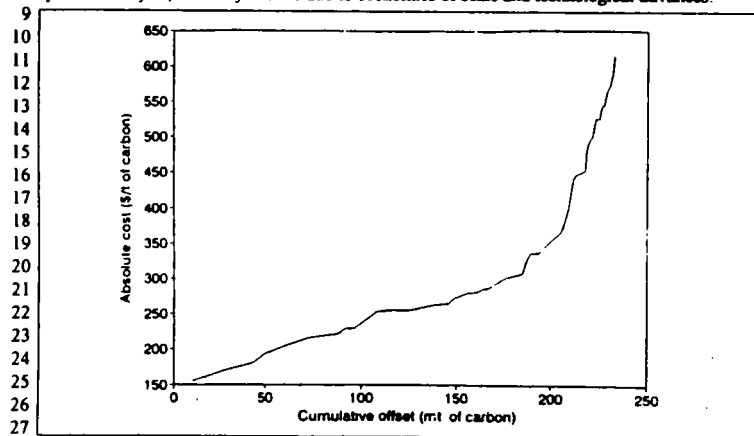
41 Figure 4.4: The marginal cost and benefits curve for an industrial country

42

43 of NO_x, SO₂ and TSP, i.e. a ratio of 3 to 1 (Assuming emissions rates for a coal-fired power plant
 44 meeting New Source Performance Standards.

45 For example, in one alternative (the "Treaty Alternative"), loss in GDP was estimated at 3.1
 46 billion Kroner, and the loss of private consumption at 2.6 billion; however joint product benefits were
 47 estimated at 2.4 billion (with a range of 1.0-3.8 billion) (Alfsen, Brendemoen and Glomsrod, 1992,
 48 p.28).

1 Another way of making the same point is by noting that single point cost estimates for many
 2 technologies can be quite meaningless, because the supply curve for even an individual
 3 technologies is not flat. For example, in the previously presented GHG emission cost curve of
 4 Figure 4.1 (for the UK), "renewables" is shown as a single block, with a single marginal cost.
 5 Yet as shown in a recent study of wind and hydro for India⁴⁸, the supply curves have the
 6 expected classical upward sloping shape as illustrated on Figure 4.6 for the supply cost of
 7 windfarms in India. Such static cost curves neglect the counter-argument that in a more
 8 dynamic analysis, cost may decline due to economies of scale and technological advances.



28 **Figure 4.8: supply cost curve for windfarms in India**

29 source: J. Hossain and C. Sinha, Limiting CO₂ emissions in the power sector of India *Energy Policy*, Oct. 1993,
 30 p. 1028.

31 5. Issues

32 Risk, uncertainty and irreversibility

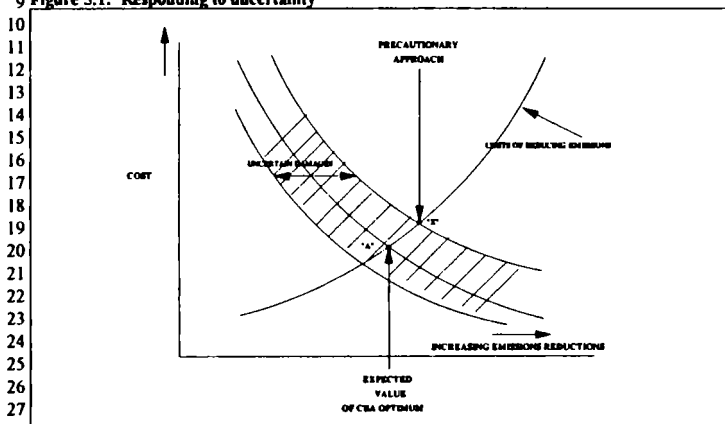
33 Our knowledge about how anthropogenic emissions of greenhouse gases affect global
 34 temperature, what kind of effects a change in global temperature may have, and how efforts to
 35 mitigate climate change may work is clearly restricted. How different greenhouse gases react in
 36 the atmosphere are not fully understood, and exact predictions of the average increase in global
 37 temperature will have different regional effects which are exceedingly difficult to foresee, even
 38 if the effect on the average temperature were taken as given. There is also considerable
 39 uncertainty about the economic and social effects of abatement measures, which are decisive for
 40 the costs and benefits of the measures.

41 One cannot, therefore, evaluate climate measures without taking these uncertainties into
 42 account. On the other hand, acknowledgment of vast uncertainties should not lead to an inert

47 ⁴⁸ J. Hossain and C. Sinha, Limiting CO₂ emissions in the power sector of India *Energy*
 48 *Policy*, Oct. 1993, p. 1028.

1 attitude, but rather to develop rational strategies for how to act under uncertainty. Economic
 2 analysis under uncertainty aims at developing strategies for decision makers that face
 3 uncertainties in their future costs and benefits. The uncertainty in the outcome of a variable is
 4 often described by a probability attached to each possible outcome. In some cases the
 5 probability distribution is objectively presented, in which cases one normally talks about risk.
 6 More often, subjective probability distributions are assumed, in which cases one talks about
 7 uncertainty.

8 **Figure 5.1: Responding to uncertainty**



29 In Section 4 we noted that the level of uncertainty in the benefits curve is greater than the
 30 level of uncertainty in the cost curve (recall Figure 4.1). Figure 5.1 illustrates the practical
 31 consequence of uncertainty in a different way. If cost abatement and damage functions were
 32 known with certainty, or if in the absence of risk aversion, one were to use expected values of
 33 the uncertain cost abatement and damage functions, then the optimum degree of emission
 34 reduction is as shown at "A". However, given uncertainty in the damage function, risk
 35 aversion leads one to a precautionary approach – at "X" – which requires more stringent
 36 emission reductions, lying to the right of the expected value point "A", and roughly determined
 37 by the intersection of the cost curve and some notional upper envelope estimate of the damage
 38 function. (There may also be some uncertainty with respect to the emissions reduction cost
 39 curve).

40 The attitude towards risky outcomes is often expressed in terms of a risk premium, which
 41 is the minimum compensation required to accept a lottery with expected return x to a certain
 42 return of x . Such a premium may be required because the decision maker prefers certain
 43 uncertain outcomes, but may also occur if the net benefit of his investment is non-proportionate
 44 in quantity. For instance, suppose a country commits itself to reduce emissions by 100 tons,
 45 and considers two alternative measures. One alternative reduces emissions by 100 tons with
 46 certainty. The other measure has a 50 percent chance of reducing them by 100 tons. Even if
 47 the expected reductions are equal, it is evident that a decision maker will prefer the certain
 48

1 alternative unless the uncertain alternative is considerably less costly, as there is a chance of
2 having to impose additional measures if unlucky. Assessments of the uncertainty involved in
3 the analysis of climate change may therefore be of great importance to decision making.

4 However, given the uncertainty it is also important to emphasize that some actions will be
5 less attractive than others. The mirror of the above argument is that some actions may be
6 acceptable even with negative net expected benefit if they reduce the uncertainty. One way to
7 do so is to spread the risk among several measures. Then, if one fails to meet its expected
8 target, another may satisfy the achievements that were expected. The total risk would thus be
9 lower than if all efforts were concentrated on one single measure.

10 One is scarcely able to account for all the uncertainties involved when analyzing climate
11 change. In some cases it may be equally difficult to assess a probability distribution of a
12 variable as a single expected estimate. Ignorance about certain effects of a measure indicate
13 that they should be left out of the analysis. However, CBA may be of great help to decision
14 making even when limited to effects on which reasonably well-founded value-estimates can be
15 provided.

16 One issue that has attained a lot of interest in the literature of environmental economics is
17 the problem of irreversible decisions under uncertainty. The reason is that environmental
18 effects, such as climate change are regarded as irreversible. If the effects turn out to be worse
19 than expected, the world is stuck with a permanent, perhaps unwanted, climatic change, which
20 clearly is worse than if the climate could be reestablished after such a change.

21 In order to incorporate the cost of irreversible effects in the CBA, a vast amount of
22 information is required – such as how the uncertainty evolves over time. Such information, is
23 rarely available, but we may assume that increased knowledge about climate change will
24 narrow the range of uncertainties in the future. If so, it has been shown that one extra cost of
25 irreversible effects is the so-called quasi option value. This value can be interpreted as the
26 value of keeping future options open, and suggests that decision makers follow flexible
27 strategies when faced with uncertainty.

28 The strategy that leaves most future options open is, however, difficult to determine.
29 Investing in abatement of climate change opens possibilities for increasing emissions at a later
30 stage if the effects turn out to be less serious than expected. On the other hand, it reduces the
31 potential use of adaptation. In addition, it is difficult to predict the effect of increased
32 knowledge, especially whether the outcomes become more certain. When dealing with many of
33 the effects of climate change, ignorance is perhaps a more appropriate concept than uncertainty.
34 Increased knowledge may change ignorance to uncertainty, but the range of possibilities will not
35 necessarily narrow for that reason.

36 In applying CBA to the global climate change problem, and in particular to the evaluation
37 of alternative policies to optimize net benefits, there are several major sources of uncertainty
38 that need to be considered⁴⁰.

39
40 1. Uncertainty over the actual rates of emission.⁴⁰ Most of the many studies cited earlier
41 make assumptions about current and future rates of emissions in some "business-as-
42 usual" case as a starting point. Current CO₂ emissions from fossil fuel use may be
43 reasonably well known, but the level of uncertainty increases as one considers levels of
44

45 ⁴⁰ This is a partial list. Other problems include the assumption that non-carbon based materials
46 are benign with respect to the GHG problem; uncertainty concerning natural sources; and uncertainty
47 over the spatial distribution of physical impacts.

48 ⁴⁰ See IPCC (1994), Chapter 6 for further discussion on uncertainty in future emissions.

1 possible fossil fuel use in the more distant future⁴¹, the impact of deforestation⁴², or the
2 emissions of other GHGs such as methane.⁴³

3 2. Uncertainty over the costs of emissions reduction. Again there are significant
4 differences between estimating the costs in electric utility systems (relatively well
5 known for conventional technologies) and those elsewhere, particularly for
6 reforestation.

7 3. Uncertainty about scientific linkages. As already noted in section 3, there exists a
8 chain of scientific uncertainty (see Figure 3.1). The extent to which these uncertainties
9 can be resolved by further research is itself subject to uncertainty (especially in light of
10 the previously noted fact that by its very nature, *ex ante* verification of models by
11 actual data is difficult. Thus it is unclear that similar arguments invoked in the context
12 of other environmental problems have validity for global climate change. For example,
13 the argument that further research was necessary on an understanding of atmospheric
14 chemistry, or of the chemistry of lake acidification, or of the exact nature of the
15 damage mechanisms on forests, before very costly efforts are undertaken to control
16 SO₂ and NO_x emissions, did at least have the merit that data on the actual damage of
17 acid rain could be found.

18 4. Uncertainty in valuing the costs and benefits of the physical impacts. Here there may
19 exist quite large variations in the level of uncertainty: for example, evaluating the cost
20 of protective dikes to protect against sea level rise, or of estimating the opportunity cost
21 of inundated land is subject to significantly less uncertainty than estimating the impact
22 on agriculture, or on biodiversity.

23 5. Uncertainty about the assumptions underlying policy options. For example, a number
24 of studies have estimated the impact on GHG emissions of eliminating subsidies on
25 coal, or on electricity, using assumed values of price elasticity.⁴⁴ General equilibrium
26 models require all kinds of assumptions about the elasticities of substitution, whose
27 actual values used in the numerical simulations are either based on historically
28 estimated elasticities, or upon the judgment of the modeler. In either case there is
29 uncertainty about the extent to which such values match actual behavior.

30 6. Uncertainty over the effectiveness of policies. For example, the proposition that a
31 certain level of carbon tax will in fact result in the hypothesized fuel substitution makes
32 a number of assumptions about the functioning of markets. As noted earlier, the very
33 fact that many apparently "no regret" options are not being implemented suggests a
34 higher level of market imperfection than economists like to admit, and/or substantially
35 higher transaction costs or discount rates.

36 7. Uncertainty about joint benefits and costs. As noted earlier, joint benefits and costs
37 may be a very significant factor in evaluating options for greenhouse gas abatement.
38 However, these joint benefits and costs are also subject to significant uncertainties (and
39 also measurement problems).

40 ⁴¹ One need only remember how dramatically growth rates and energy/GDP ratios
41 changed in the decade following the 1973 oil crisis to recognize the hazards of such forecasts.

42 ⁴² This issue is made more complicated by the fact that much deforestation is presently driven
43 by the need to expand pasture land, which in turn implies higher methane emissions from livestock.

44 ⁴³ For a full discussion of uncertainty in emissions, see e.g. Ebert and Karmali (1992).

45 ⁴⁴ see note 46, *supra*.

1 The application of valuation techniques is difficult even where the impacts themselves can be
 2 quantified with relative confidence. But in the case of global climate change, however,
 3 uncertainties in economic valuation techniques may be significantly smaller than the *scientific*
 4 uncertainties that surround the impacts of increasing concentrations of greenhouse gases.
 5 Advocates of immediate mitigation action to reduce emissions argue that even if the probability
 6 of some of the important impacts are unknown, and subject to great uncertainty, they are not
 7 zero. Low probability, high impact events are especially complex to model, and may also elicit
 8 counter-intuitive public reaction due to extreme risk-averse behavior (e.g. nuclear accident).
 9 Further, the process of climate change, once underway, will be irreversible (at least during a
 10 period measured in centuries), and the damages which may result are so catastrophic, that
 11 action may be warranted even in the absence of more precise scientific knowledge about the
 12 impacts.

13 A good analogy is a nuclear power plant accident. The Chernobyl incident
 14 notwithstanding, the risk of catastrophic accident is extremely small. But the cost of a major
 15 accident is undoubtedly very large. Both the probabilities⁵⁵, as well as the cost of the impacts,
 16 are very difficult to estimate. But even if one could agree on appropriate values to use, and one
 17 were able to calculate an expected value, decision-making on the basis of the expected value
 18 may still not reflect the preferences either of the public or of decision-makers. The
 19 consequences of even an extremely unlikely event may be perceived as so undesirable
 20 (especially in the case of extreme risk aversion), that "normal" decision rules may simply not be
 21 viewed as appropriate. In other words, cost-benefit analysis must deal not just with expected
 22 values, but also with risk preferences of the decision-makers, and those they represent.

23 The traditional and simple way of incorporating uncertainty considerations in CBA has
 24 been through sensitivity analysis. Using optimistic and pessimistic values for different
 25 variables can indicate which variables will have the most pronounced effects on benefits and
 26 costs. While sensitivity analysis need not reflect the probability of occurrence of the upper or
 27 lower values, it is useful for determining which variables are most important to the success or
 28 failure of a project (Dixon *et al.* 1988). Indeed decision-makers often assign (even if only
 29 implicitly) probabilities to the various outcomes. Admittedly, the sheer magnitude of the costs
 30 of catastrophic climate change will make the sensitivity analysis problematic.

31 One might note that for certain types of uncertainty, something akin to risk insurance is
 32 available in the form of futures and options markets. For example, one can hedge against
 33 uncertainty in the future price of oil by transactions in the oil futures markets, but their efficient
 34 functioning depends upon there being some balance between those who are buyers of oil (who
 35 are primarily interested in protecting themselves against a rise in the price), and sellers of oil
 36 (who are interested in protecting themselves against a fall in the price of oil). (See Box 2)⁵⁶.

37 Finally, extreme uncertainty might also influence the nature of the economic instruments
 38 employed for policy purposes. For example, a price-oriented mechanism (such as a carbon tax)
 39 which limits economic dislocation might be preferred over a quantity-based mechanism (such as
 40 tradable permits) in a situation where there are both uncertain control costs and an uncertain
 41 environmental response (see Lave and Gruenspecht, 1991).⁵⁷

42 " The US Nuclear Regulatory Commission has made repeated attempts to establish probabilities
 43 for specific kinds of accidents through a technique known as fault tree analysis. Despite the
 44 appearance of scientific rigor, the resultant probability estimates remain highly controversial. For
 45 examples of the use of cost-benefit analysis by the US NRC, see e.g. Mubayi *et al.* (1991) or
 46 Abrahamson *et al.* (1989).

47 " Precautionary expenditures may also be influenced by aversion to catastrophic risks. A recent
 48 example is the hundreds of billions of dollars per year spent in the U.S. to avert soviet nuclear attack

Box 2: Applications of decision analysis

Option analysis. In conventional CBA analysis, the usual decision rule is to take some action if the expected benefits exceed the expected costs. Depending on the degree of irreversibility present, a more appropriate rule is to take the action when benefits exceed costs by an amount at least equal to the value of the forgone option. Suppose some investment depends upon some assumptions that are subject to great uncertainty – such as future world oil prices. If one makes some investment decision that is largely irreversible – such as building a large hydroelectric power project – then one loses the flexibility associated with waiting to learn more about the factors that affect oil prices. Preserving that flexibility has some economic value, namely the so-called option value. In financial and commodity markets such options to buy (and sell) are traded, with option prices determined by the market itself. But option value theory is now being applied to other fields involving capital intensive investments – such as power generation.¹

In applying these concepts to the climate change problem, there are of course many key differences. First, in one sense the problem is exactly opposite to that faced, say, by the power sector. In climate change, one loses flexibility if one does *not* make short-term investments to reduce GHG emissions. Second, unlike in the financial and commodity context, there is no marketplace to set the value of the option.²

Decision analysis and hedging strategies. Among the early attempts at applying decision analysis to the climate change problem are those of Manne and Richels,³ who have developed an approach for determining the optimal hedging strategy. The paradigm they use is that of a portfolio of insurance options:⁴ what combination of insurance should be bought, if indeed any at all? "...what portion goes to R&D to resolve scientific uncertainties? What portion goes to the development of new supply and conservation technologies to reduce abatement costs? And what portion goes to immediate abatement of emissions? Particularly they focus on the value of information⁵ how much accuracy is needed in climate modeling and impact assessment? Clearly, with *perfect information*, the best course of action can be charted immediately, and there is no need to hedge bets. Manne and Richels conclude that the need for precautionary near-term emissions reductions is inversely related to the sustained commitment to R&D to develop better climate information (which reduces the need to hedge against an uncertain and potentially hostile future). However, given the inherent predictive uncertainty of climate change, (and in particular the reliability of indicators), the limitations of such approaches need to be recognized.

¹ See e.g. E. Crousillat and S. Martzoukos, *Decision-making under uncertainty: An option valuation approach to power planning*, Industry and Energy Department Working Paper, Energy Series Paper 39, World Bank, Washington, DC, 1991. This study reviewed power sector investment decisions in Costa Rica, Hungary and West Africa. For a general review, see Dixit and Pindyck (1994).

² A marketplace might of course emerge if a tradable emissions permit system were to be instituted. Chao and Wilson (1993) outline a means of using option values to quantify the flexibility associated with the purchase of a tradable emissions permit instead of fixed capital investment in control technology.

³ See e.g. A. S. Manne and R. Richels, *Buying greenhouse insurance: the economic costs of carbon dioxide emission limits*, MIT Press, Cambridge, MA, 1992.

⁴ I. Lave (*Are economists relevant? The efficiency of a carbon tax*, in Dornbusch and Poterba (Eds) *Climate Change: Economic Policy Responses*, MIT Press, Cambridge, MA, 1991) notes that the concern about global climate change is not merely concentrated in the rich nations, but in the upper income groups in those nations. These are the same groups that voluntarily purchase insurance to protect themselves against other losses: health, flood, earthquake. Persuading poor people to buy flood or earthquake insurance is exceptionally difficult even in the developed countries.

⁵ The value of information under uncertain conditions is a concept much used in the private sector. For example, in oil exploration, before drilling a wildcat well – a very expensive proposition – the question arises as to how much ought to be spent in much less expensive prior survey work: general magnetic surveys, or more expensive seismic surveys? Neither yields perfect information. For details of how such decision-theory models are applied in this field, see e.g. Newendorp (1976).

2 Valuation

The robustness of a cost-benefit analysis depends critically on how reliable the values attached to each item are. The prices of marketable goods and services express social values as long as the goods in question are not rationed and there are no externalities.⁵⁸ For non-marketed goods and services, such as many environmental services, values have to be estimated in order to aggregate costs and benefits and obtain an overall evaluation of choice of policy. Estimated prices may depend on the methodology chosen to create them, and one should therefore interpret results which include such prices with caution.

One reason why avoiding climate change may have a value is that climate change will cause a change in economic activities. Sea level rise will force people to move, more turbulent weather conditions may increase the need for rebuilding of damaged materials etc. A second reason is that people attach subjective values to the climate where they live, to some extent reflected in the notions of "good" and "bad" weather.

However it is difficult to assess these values. To simplify somewhat, one may base an estimate on the anticipated costs of achieving a certain target at observed market prices, for instance the minimum abatement cost of attaining the same level of greenhouse gases emissions as a previous year. Alternatively, one may estimate the willingness to pay for reaching such a target. In neither of the cases, however, would one be able to assess the equilibrium price, or the value. The choice of approach might therefore be strictly decisive for the conclusion, for instance if pollution that causes severe damage (high willingness to pay) could be avoided by low costs.

Valuation of environmental effects in CBA may be helpful in attaining cost-effective decisions. However, the valuation should be based on a reasonably well founded methodology. Speculative assumptions will not contribute to decision making. A measure which yields negative net benefits according to an analysis may be worthwhile to accept if effects that are assumed to be positive but not explicitly valued in the calculation are well documented. Decision makers will normally manage to consider more than one measure simultaneously. CBA usually simplifies the decision by aggregating several effects, but there is no necessity for all effects to be aggregated into one single measure.

There are several fundamentally different types of costs and benefits that must be addressed, each of which requires somewhat different approaches to quantification and valuation:

1. Mitigation actions taken before the actual impacts are observed. These are primarily a matter of emissions reductions, or of removing GHGs through reforestation. The vast majority of the applications of cost-benefit analysis have addressed the question of how

Perhaps there is a possible role of financial markets for insuring (and pricing) environmental risks (just as utilities can insure or self-insure against environmental damages caused by accidents at plant sites), but since the damage estimates related to climate change are very difficult to assess, the opportunities for such a approach seem limited, even if the probability of occurrence could be estimated more accurately.

If prices of marketed goods are distorted (e.g. due to arbitrary taxes and subsidies), it will be necessary to use shadow prices – usually the set of economic opportunity costs or efficiency prices – to determine the set of opportunity costs or efficiency prices – to determine their correct economic value (for details, see DasGupta *et al.*, 1972, Little and Mirrlees, 1974)

best to achieve given levels of emission reduction reductions. Valuation issues generally do not arise in this category.

2. Costs of mitigation actions taken after impacts become apparent. These will necessarily occur in the future, and would be undertaken only if (1) climate change actually does occur, and (2) that climate change does in indeed result in specific impacts. The cost of dikes to prevent inundation of coastal areas is a typical example in this category: based on actual experience (such as in the Netherlands) the cost of such mitigation actions are relatively easy to establish.⁵⁹ Climatic engineering options also fall in this category, such as painting roads and roofs white, or putting particles into the stratosphere. Again there are few valuation issues here.

3. Costs (and benefits) of Adaptation. Society will adapt with varying degrees of pain to many of the impacts of climate change – indeed, society has already adapted to changes in climate that have occurred over the past 1000 years. For example, climate change will affect crop yields, and result in poleward shifts in cultivated land. Some areas will gain, and some will lose, which becomes an equity issue (between regions and countries) as much as a cost issue. Estimates of net losses for U.S. agriculture, for example, suggest a tolerable impact for the U.S. as a whole, but significant regional variations.⁶⁰ Some of the costs of adaptation will vary, depending on ex-ante actions (e.g. more agricultural R&D expenditure to develop drought or saline resistant crops)⁶¹

4. Costs (and benefits) of non-adaptation. In some cases, adaptation may not be possible, and/or the cost of mitigation may be higher than the loss incurred in its absence. For example, in some areas, the cost of construction of dykes may be far higher than the value of the land lost to coastal flooding, in which case the relevant cost to be estimated for purposes of CBA is the value of the land lost.

It is thus in the third and fourth of these categories that valuation issues arise. Table 5.1 lists the specific categories of impacts that may be encountered as a result of global climate change.

Conceptually, the total economic value (TEV) of a resource consists of its use value (UV) and non-use value (NUV).⁶² Use values may be broken down further into the direct use value (DUV), the indirect use value (IUV) and the option value (OV) (potential use value)⁶³ One needs to be careful not to double-count both the value of indirect supporting functions and the value of the resulting direct use. One major category of non-use value is existence value (EV). Thus

It should be noted that the distinction between a mitigation measure and an adaptation measure

⁵⁹ "Preliminary results suggest that although US crop production could decline, supplies would be adequate to meet domestic needs" (EPA, *op.cit.*, 1989, p 93). It might well be pointed out, however, that this reflects the very narrow perspective of the study: U.S. grain exports represent a significant supply of food for developing countries, and were the U.S. surplus to decline, developing countries may well be concerned about the use of food exports as a political weapon.

⁶⁰ Particularly difficult to value is the cost of forced adaptation and population movements – a problem already encountered in cost-benefit analysis of the impact of large reservoirs where significant numbers of individuals must be forcibly re-located

⁶¹ For further details, see Munasinghe (1993), Pearce and Warford (1993).

⁶² The issue of option values and irreversibility in CBA has received increasing attention in the literature, starting with Arrow and Fischer (1974), and more recently by Chichilinsky and Heal (1994)

$$TEV = UV + NUV$$

$$TEV = [DUV + IUV + OV] + [NUV]$$

Table 5.1: Potential impacts to be valued (for the U.S.)¹

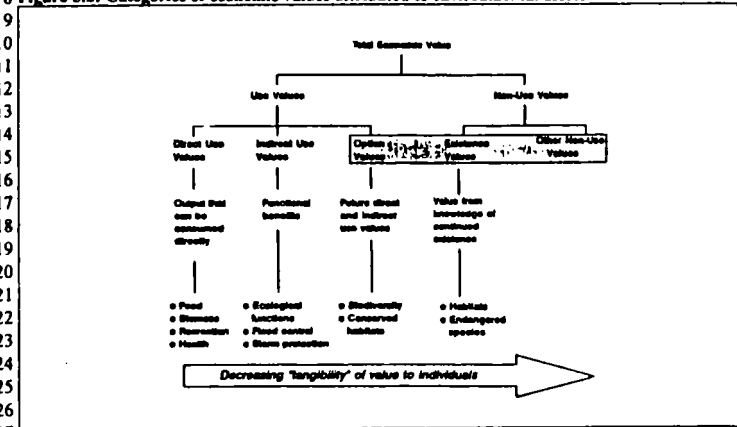
Systems	Potential Impacts
forests/terrestrial vegetation	migration of vegetation reduction in inhabited range altered ecosystem composition
species diversity	loss of diversity migration of species invasion of new species
coastal wetlands	inundation of wetlands migration of wetlands
aquatic ecosystems	loss of habitat migration to new habitat invasion of new species
coastal resources	inundation of coastal development increased risk of flooding
water resources	changes in supplies changes in drought and floods changes in water quality/hydropower production
agriculture	changes in crop yields shifts in relative productivity and production
human health	shifts in range of infectious disease changes in heat-stress and cold-weather afflictions changes in fertility due to stress
energy	increase in cooling demand decrease in heating demand changes in hydropower output
transportation	fewer disruptions in winter transportation increased risk for summer inland transportation risks to coastal roads
also considered in EPA study	
air quality	
other impacts not considered in OTA or EPA studies	
weather-related damages	damages related to changes in the frequency and severity of extreme weather events like storms.
amenity value	
construction industry	

¹ Systems and potential impacts as listed in OTA, *op. cit.*, p.15.

Figure 5.2 shows this disaggregation of TEV in schematic form. Below each valuation concept, a short description of its meaning and a few typical examples (based on a tropical rainforest) of the environmental resources underlying the perceived value, are provided. Option values and non-use values and existence values are shaded, to caution the analyst concerning some of the ambiguities associated with defining these concepts – as shown in the examples, they can spring from similar or identical resources, while their estimation could be interlinked also. However, these concepts of value are generally quite distinct. Option value is based on how much individuals are willing to pay today for the option of preserving the asset for future (personal) direct and indirect use (see Box 2). In the context of uncertainty, quasi-option value is said to define the value of preserving options for future use in the expectation that knowledge

will grow over time – about the potential benefits or costs associated with the option (see Pearce and Turner, 1990, and Fisher and Haaneman, 1987). This approach may be quite relevant, given the great uncertainties associated with climate change. Existence value is the perceived value of the environmental asset unrelated either to current or optional use, i.e., simply because it exists. A variety of valuation techniques may be used to quantify the above 6 concepts of value.⁴⁴

Figure 5.2: Categories of economic values attributed to environmental assets.



The basic concept of economic valuation underlying all these techniques is the willingness to pay (WTP) of individuals for an environmental service or resource, i.e., the area under the compensated or Hicksian demand curve.⁴⁵ As shown in Box 3, valuation methods can be categorized according to which type of market they rely on, and by considering how they make use of actual or potential behavior.

⁴⁴ For a recent overview of techniques suitable for valuing environmental costs and benefits, especially in developing countries, see Munasinghe (1993).

⁴⁵ Problems of measurement may arise because the commonly estimated demand function is the Marshallian one – which indicates how demand varies with the price of an environmental good, while keeping the user's income level constant. In practice, it has been shown that the Marshallian and Hicksian estimates of WTP are in good agreement for a variety of conditions, and in a few cases the Hicksian function may be derived once the Marshallian demand function has been determined (Willig, 1976, Kolstad and Braden, 1991). What people are willing to accept (WTA) in the way of compensation for environmental damage, is another measure of economic value that is related to WTP. WTA and WTP could diverge (Cropper and Oates, 1992). In practice either or both measures are used for valuation.

Box 3: Taxonomy of valuation techniques

TYPE OF BEHAVIOUR	TYPE OF MARKET		
	conventional market	implicit market	constructed market
Based on actual Behaviour	effect on production	based cost	artificial market
	effect on health	wage differential	
	defensive or preventive costs	property values	
Based on intended behaviour		proxy marketed goods	
	replacement cost		contingent valuation
	shadow project		

Effect on Production. An investment decision often has environmental impacts, which in turn affect the quantity, quality or production costs of a range of productive outputs that may be valued readily in economic terms.

Effect on Health. This approach is based on health impacts caused by pollution and environmental degradation. One practical measure related to the effect on production is the value of human output lost due to ill health or premature death. The loss of potential net earnings (called the human capital technique) is one proxy for foregone output, to which the costs of health care or prevention may be added.

Defensive or Preventive Costs. Often, costs may be incurred to mitigate the damage caused by an adverse environmental impact. For example, if the drinking water is polluted, extra purification may be needed. Then, such additional defensive or preventive expenditures (ex-post) could be taken as a minimum estimate of the benefits of mitigation.

Replacement Cost and Shadow Project. If an environmental resource that has been impaired is likely to be replaced in the future by another asset that provides equivalent services, then the costs of replacement may be used as a proxy for the environmental damage - assuming that the benefits from the original resource are at least as valuable as the replacement expenses. A shadow project is usually designed specifically to offset the environmental damage caused by another project. For example, if the original project was a dam that inundated some forest land, then the shadow project might involve the replanting of an equivalent area of forest, elsewhere. **Travel Cost.** This method seeks to determine the demand for a recreational site (e.g., number of visits per year to a park), as a function of variables like price, visitor income, and socioeconomic characteristics. The price is usually the sum of entry fees to the site, costs of travel, and opportunity cost of time spent. The consumer surplus associated with the demand curve provides an estimate of the value of the recreational site in question.

Property Value. In areas where relatively competitive markets exist for land, it is possible to decompose real estate prices into components attributable to different characteristics like house and lot size, air and water quality. The marginal WTP for improved local environmental quality is reflected in the increased price of housing in cleaner neighborhoods. This method has limited application in developing countries, since it requires a competitive housing market, as well as sophisticated data and tools of statistical analysis.

Wage Differentials. As in the case of property values, the wage differential method attempts to relate changes in the wage rate to environmental conditions, after accounting for the effects of all factors other than environment (e.g., age, skill level, job responsibility, etc.) that might influence wages.

Proxy Marketed Goods. This method is useful when an environmental good or service has no readily determined market value, but a close substitute exists which does have a competitively determined price. In such a case, the market price of the substitute may be used as a proxy for the value of the environmental resource.

Artificial Market. Such markets are constructed for experimental purposes, to determine consumer WTP for a good or service. For example, a home water purification kit might be marketed at various price levels, or access to a game reserve may be offered on the basis of different admission fees, thereby facilitating the estimation of values.

Contingent Valuation. This method puts direct questions to individuals to determine how much they might be willing-to-pay (WTP) for an environmental resource, or how much compensation they would be willing-to-accept (WTA) if they were deprived of the same resource. The contingent valuation method (CVM) is more effective when the respondents are familiar with the environmental good or service, and have adequate information on which to base their preferences. Recent studies indicate that CVM, cautiously and rigorously applied, could provide rough estimates of value that would be helpful in economic decision-making, especially when other valuation methods were unavailable.

Source: Munasinghe (1993)

Valuation techniques obviously need to be selected with some care, and in particular one must recognize that a particular valuation technique may not necessarily capture the entire value. For example, if the replacement cost approach is being used to value the loss of forest area being inundated by a dam, it would likely capture only the *use* value. The value of biodiversity loss involved in the loss of primary forest, or a developed ecosystem, may not be included.⁴⁵

We note that these valuation techniques have been developed for more conventional environmental impact analysis, and would require significant modification and/or careful interpretation when applied to global climate change (e.g. long-term intergenerational impacts, biodiversity loss, welfare comparisons across cultures, or where there are wide gaps between gainers and losers, etc.). Nevertheless, whatever may be the difficulties, the importance of valuation remains, and the development of better techniques should be viewed as an important item in the overall climate change research agenda. Certainly ignoring an impact because it cannot be satisfactorily valued carries high risk, and is one of the reasons for the use of MCA (see below).

Discount rate

We noted in the introduction that CBA requires a very specific and explicit way of dealing with time. The first principle is that past (or "sunk") costs are ignored, based on the premise that 20 since past decisions cannot be changed, they have no bearing over decisions regarding the 21 efficiency of resource use that are to be made in the present or in the future.⁴⁷

The second principle is that a discount rate is applied to future costs and benefits to yield 23 their present values. The issue of choosing an appropriate discount rate has been discussed in 24 the context of general CBA for many years (Dasgupta et al. 1972, Harberger 1976, Little and 25 Mirrlees 1974, Sen 1967). The long term perspective required for sustainable development 26 suggests that the discount rate might play a critical role in intertemporal decisions concerning 27 the use of environmental resources (Lind and Arrow 1982). We briefly discuss below, several 28 key issues relating to discount rates - the topic is dealt with more fully in Chapter 4.

Compared with most other economic investment decisions, the time perspective of 30 measures aiming at mitigation of climate change is considerably longer. Cline (1992) suggests 31 a 200 - 300 years time horizon for climate policy decisions, while investments in economic 32 activities seldom need more than a 25 years horizon. This makes assumptions about how the 33 economic and the environmental systems will develop, and the discounting of values that occurs 34 in the future critical to the evaluation of measures.

The discount rate denotes the social opportunity cost of capital. It reflects total social 36 benefits if one unit of present output is withdrawn from consumption and instead is invested 37 (for instance in production or abatement). The criteria for optimal social and economic 38 development is that the marginal total benefits from the different investments should be equal 39 regardless of what the investments are aiming at. In other words, the social discount rate

⁴¹ Contingent Valuation methods in particular are somewhat controversial, and need great care 42 in their application to produce credible results.

⁴³ One needs to take note also of the fact that this principle is also not universally accepted, 44 particularly by political leaders. The principle that "past sacrifices ought not to be in vain" is 45 frequently invoked as relevant to present decisions. Indeed, in the climate change debate, developing 46 countries correctly note that it is the developed countries who are largely responsible for the present 47 levels of GHG in the atmosphere, and that this past behavior is relevant in the search for equitable 48 solutions in the future. However, these observations point to the *equity* dimension of the problem, and do not affect how one ought to seek the economically efficient options.

1 should be equal for all investments. If not, it would be possible to reallocate resources and
2 attain a higher social benefit without any cost. Thus, the discount rate expresses a condition for
3 dynamic (or intertemporal) efficiency.

4 The discount rate also provides a signal to decision makers who evaluate single projects
5 or measures to take decisions in accordance with dynamic efficiency (over time). Even if one
6 accepts the requirement to apply the same discount rate for marginal projects within a given
7 time period, there are many potential optimal levels of the discount rate. This level depends,
8 *inter alia*, on the social preferences about present versus future consumption which may be
9 reflected by an intertemporal welfare function. The formulation of this function has been the
10 subject of an extended debate in which questions about intertemporal comparisons as well as
11 current welfare contributors have been raised.

12 It is worth emphasizing that although externalities related to climate change will affect the
13 social rate of discount, it is not sufficient to merely adjust this discount rate in order to take full
14 account of climate change in a CBA. One must include also the "price" of the environment,
15 which may increase substantially over time. As a consequence, future impacts from climate
16 change may be quite important to present day decisions, even in "discounted terms": A five per
17 cent increase in the price of the environment will fully counteract the effect of a five per cent
18 discount rate.

19 To conclude, discounting is necessary in order to compare costs and benefits at different
20 time periods. Attempts to avoid discounting or to apply a different discount rate for climate
21 measures than other investments will inevitably result in an inefficient policy. However, it is
22 difficult to pick out the correct level for the optimal social rate, as there are no practical
23 observations of such a rate. Furthermore, discount rates may depend on the future scenario that
24 is assumed, and could vary over time – in particular very long term discount rates may be
25 lower as economic growth rates saturate and decline.⁴⁶

26 CBA and Equity

27 The benefits and costs of climate change mitigation strategies may accrue to different countries
28 (and to different regions within larger countries). How one reconciles these differences is
29 therefore one of the central dilemmas facing policy-makers: and the equity issues involved are
30 discussed in some detail in Chapter 4.

31 Thus, while CBA can provide answers on who should engage in how much abatement
32 based solely on the criterion of maximizing economic efficiency, it must be recognized that
33 some deviation from the global least-cost solution as obtained by CBA may have to be accepted
34 in order to get international agreement. As indicated earlier on Figure 2.1, there will likely be a
35 trade-off between equity objectives and economic efficiency: CBA can help define the trade-off
36 curve, but it cannot provide an answer to what combination of economic efficiency and equity is
37 necessary to get international agreement. However, whether there is a trade-off between equity
38 and efficiency (and the properties of this trade-off) depend upon what policy instruments are
39 available. For example, if one permits side-payments (of some kind) between countries, the
40 efficient allocation of emissions across countries is independent of the equity issue.

41 Several concerns shape equity perceptions and the ability to obtain international
42 agreements. Effective action to control climate change is dependent on a degree of international
43 agreement. Therefore a first obstacle to whatever mechanism might be agreed upon is national
44 sovereignty – to what extent will sovereign nations subject themselves to enforcement actions

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46
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48 ⁴⁶ For a discussion, see Munasinghe (1993).

1 by others? Even simple agreements for joint implementation of projects involving two countries
2 have run into difficulties (see below).

3 The second obstacle is the heterogeneous nature of the effects of greenhouse warming.
4 Although the most widely cited measure of climate change is the average increase in global
5 temperature, climate change affects different countries differently. In addition, the costs or
6 response measures and their economic implications vary greatly among countries, particularly
7 as a function of the level of development. Therefore the perceptions of benefits of global
8 cooperation will differ greatly.

9 A third obstacle is posed by strategic incentives. If some countries take the lead and set
10 up a greenhouse gas agreement, others have an incentive to free-ride and abstain from joining,
11 as they cannot be excluded from the benefits such an agreement creates. If countries act
12 selfishly in this way, few will become party to an agreement. Most countries will therefore not
13 cooperate and no general agreement will be reached even if all countries were to benefit from it.
14 (This is the well known prisoner's dilemma from game theory).⁴⁹ Some argue that the
15 overwhelming historical contribution to the build-up of GHGs from developed countries
16 constitutes an "environmental debt", that cannot be conveniently ignored using the traditional
17 "sunk cost" approach. If past contributions to GHG emissions are considered from an equity
18 viewpoint, establishment of appropriate side-payment mechanisms from developed to
19 developing countries, including financial assistance and technology transfer, could facilitate the
20 more enthusiastic cooperation of developing countries in climate change mitigation efforts.

21 The question of joint implementation illustrates the limits of CBA in this regard. The
22 motivation for joint implementation is a straight forward result of CBA. If a country – say the
23 U.S. – decides to make an effort to reduce GHG emissions, and if reductions can be obtained
24 at lower costs abroad, then the US should initiate projects in other countries in order to
25 minimize overall costs (Aaheim, 1993). The receiving country has nothing to lose if the
26 additional cost of such a joint implementation project is covered by the investing nation. Yet
27 many countries and organizations have reacted with skepticism, for reasons that are political,
28 and based on equity concerns, rather than on economic efficiency. The reasons include the
29 mistrust of the true willingness of the industrial countries to mitigate climate change; the belief
30 that the ultimate reduction in GHGs under such a regime would be negligible; and the suspicion
31 that joint implementation gives industrial countries an opportunity to "buy themselves out of
32 their problems" at the expense of the developing countries.⁵⁰ Indeed, some developing
33 countries fear that joint implementation investment might partly substitute for traditional forms
34 of financial and donor assistance, and that such agreements might preclude the right of future
35 generations to emit GHGs.

36 Brazil and other countries have advanced a further reason for host country skepticism of
37 joint implementation projects, namely that Annex I countries to the Rio Convention would
38 invest in all of the low cost/high return projects, and thus non-Annex I countries required to
39 curb emissions would find the cheapest and best options already taken up. Such an extension of

40
41
42 ⁴⁹ However, for a criticism of this argument, see e.g. Brown (1992), who points out that some
43 European countries have already taken unilateral action to reduce greenhouse gases, in hopes that
44 others will follow. Moreover, other game-theory paradigms have been proposed for modeling
45 international environmental negotiations: for example, Carraro and Siniscalco (1992, 1993) propose a
46 "chicken game" framework belonging to the class of coordination games.

47 ⁵⁰ For a discussion of these issues, and a discussion of how CBA can make a contribution to the
48 evaluation of such projects, see Aaheim (1993). Concerns about "market justice" and related
considerations are outlined in Rose (1990).

1 non-Annex I parties' commitments, to higher income developing countries has recently been
2 proposed by Australia at INC 10.

3 4 Multicriteria analysis

5
6 Even the staunchest advocates of cost-benefit analysis would concede that economic efficiency
7 (or economic value) is not the sole criterion in setting public policy, and that policy-makers
8 rightfully need to consider a broader set of objectives. Unfortunately there is much confusion
9 about what constitutes a coherent set of objectives. Table 5.2, taken from a major EPA study,
10 lists the criteria suggested there as constituting the basis for selecting public policy; the authors
11 go on to note that the first four criteria listed – flexibility, urgency, irreversibility and low cost –
12 "...would generally be given the highest priority". Note that many of these criteria overlap with
13 each other, and economic efficiency is among them!

14
15 Table 5.2: Criteria for choosing a strategy

- | | |
|----|--|
| 16 | 1. Flexibility |
| 17 | 2. Urgency |
| 18 | 3. Low cost |
| 19 | 4. Irreversibility |
| 20 | 5. Consistency |
| 21 | 6. Economic Efficiency |
| 22 | 7. Profitability |
| 23 | 8. Political feasibility |
| 24 | 9. Health and Safety |
| 25 | 10. Legal and administrative feasibility |
| 26 | 11. Equity |
| 27 | 12. Environmental quality |
| 28 | 13. Private v. Public sector |
| 29 | 14. Unique or critical resources |

30
31 Source: EPA, *The Potential effects of global climate change*
32 on the United States, EPA-230-05-89-050,
33 Washington, DC, December 1989, p.390.

34 Simple applications of CBA tend to focus only on economic efficiency. However, in more
35 recent extensions, traditional CBA concepts are embedded in MCA, that expressly allows more
36 than one objective, and expressly addresses risk and uncertainty – thereby providing an
37 integrating mechanism for most of the criteria listed. Multicriteria analysis techniques first
38 gained prominence in the 1970s, when the intangible environmental externalities lying outside
39 conventional cost-benefit analysis (CBA) methodologies were increasingly recognized. It also
40 met one objective of modern decisionmakers, who preferred to be presented with a range of
41 feasible alternatives – as opposed to one "best" solution. MCA also allows for the appraisal of
42 alternatives with differing objectives and varied costs and benefits, which are often assessed in
43 differing units of measurement.

44 Thus, upon closer examination of the criteria listed on Table 5.2, criteria 1, 2, 3, 4, 5, 6
45 can all be treated by modern decision-analysis: indeed, questions of timing (urgency), flexibility
46 (or robustness), capital constraints ("low cost") are all central elements of the approach.
47 Criterion 13 is really part of 6 (in the text the authors of the EPA report amplify the criterion
48 as follows: "Does the strategy minimize governmental interference with decisions best made by
the private sector"?). Furthermore, modern valuation techniques permit substantial parts of
Criteria 9 and 12 to be included in the economic analysis as well. As conceded by the EPA

1 report (p.393), "if the principal costs and benefits can be quantified in monetary terms,
2 economic theory provides a rigorous procedure for making trade-offs between present and
3 future costs, and for considering uncertainty, profitability, and most of the other criteria".

4 There is also a need to separate the basic goals of public policy – such as economic
5 efficiency and equity – which surely have primacy, from implementation issues such as legal
6 and administrative feasibility, which are generally secondary. The premise of CBA analysis is
7 that one looks first at the primary objectives, and then asks how much of the primary objectives
8 one may have to sacrifice to achieve practical implementation. This principle has become
9 accepted in many areas of policy-making. For example, the starting point for setting electric
10 utility rates is to calculate the economically efficient tariff (based on marginal costs), and then
11 make adjustments to protect low income groups (through lifeline rates, special provisions for
12 disconnection in the event of non-payment, etc.). The essence of the approach is not that
13 non-economic issues are ignored, but that the trade-offs between economic efficiency and equity
14 (or indeed other objectives not readily monetized) are explicitly quantified and displayed in such
15 a manner that decision-makers are made aware of how much of one objective is traded off in the
16 interests of the other.

17 Indeed, one of the advantages of MCA is that it forces political decision-makers to look at
18 the trade-offs between their major objectives, rather than attempting to boil down everything
19 into a single number, particularly where valuation techniques may be controversial. Nowhere is
20 this more important than in valuation of human life.⁷¹

21 The application of MCA methods involves the following steps:

- 22 1. Selection and definition of attributes, say A_i , $i=1, \dots, N$, selected to reflect important planning
23 objectives. While the two major relevant attributes in the context of the global climate change
24 problem are cost and GHG emission reductions, we have already noted that strategies to
25 control GHG emissions may have other side-effects, some positive, and some negative, which
26 may also difficult to value, and which might therefore require additional attributes (such as,
27 for example, for biodiversity)
- 28 2. Quantification of the levels A_{ij} of the i attributes estimated for each of the j alternatives. In
29 this quantification, full consideration must be given discounting issues, for non-economic and
30 economic attributes alike. At this stage of the analysis, trade-off curves are powerful tools to
31 communicate with decision-makers: they are particularly relevant in a situation, such as the
32 climate change problem, where the quantification of benefits may be difficult, and where
33 decision-makers must act largely on the basis of trading-off short-term costs against certain
34 levels of GHG emission reduction.
- 35 3. Determination and application of a decision rule, which amalgamates the information into a
36 single overall value or ranking of the available options, or which reduces the number of
37 options for further consideration to a smaller number of candidate plans. Where
38 amalgamation is contemplated, attribute levels are first translated into a measure of value,
39 $v(A_{ij})$ (also known as the attribute value function).⁷² This is sometimes combined with a

40 ⁷¹ Differential valuation of human lives is strenuously opposed by some: if a U.S. life is worth
41 \$1.5 million, then so is everyone else. On the other hand, when making comparisons of per capita
42 GDP, economists are increasingly turning to purchasing power parity adjustments in an attempt to
43 make more valid comparisons of economic level. MCA avoids these difficulties by removing
44 judgments about the value of human life from the domain of technical assessment, into the domain of
45 political decision-making, where making such judgments properly belong.

46 ⁷² MCA deals with attitudes toward risk and uncertainty at this stage by the use of
47 multi-attribute utility functions, which explicitly capture attitudes toward risk (see Keeney and Raiffa,
48 1976; Keeney and Wood (1977) for an application in water resource planning, or Keeney and von
Winterfeldt (1987) for application to electric utility planning).

1 normalization procedure usually on a scale of zero to one (in which the lowest value of the
2 attribute value function is assigned zero, the highest one). Subsequently weights w_i for each
3 attribute must be determined to arrive at the overall amalgamation.

4 Trade-off curves are a particularly useful tool for analysis of energy-environmental policy
5 options. Figure 5.3, taken from a recent study of options for greenhouse gas (GHG) emission
6 reductions in Sri Lanka (Meier, Munasinghe and Siyambalapitiya, 1993), illustrates the
7 essential concepts. The figure is a plot of two attributes -- GHG emissions and total system
8 costs -- for the technology options identified on Table 5.4. Each point represents a perturbation
9 of the reference case, defined as the official 1993 basecase capacity expansion plan of the CEB.
10 The *trade-off curve* is the set of options that are not dominated by others (sometimes
11 referred to as the "non-inferior set"). These are the options that are "closest" to the origin, and
12 therefore represent the "best" set of options that merit further attention.⁷³

13 Several useful concepts arise here. First is the concept of *dominance*.⁷⁴ PFBC (a clean
14 coal technology) is said to dominate the options in the sector shown, namely FGD, wind and
15 *FGD. PFBC has better costs and better (lower) GHG emissions, and is thus preferred over
16 these options under both criteria. If only these two attributes mattered, then there would be no
17 reason to select any of the dominated options in place of PFBC.

18 Another perspective is gained by dividing the solution space into quadrants with respect
19 to the reference case (Figure 5.4). The options that fall into quadrant III are the "win-win"
20 options, which are better than the reference case in *both* attributes. In this case, mini-hydro,
21 energy efficient refrigerators, T&D system loss reduction and compact fluorescents all fall into
22 this quadrant, providing both cost and emission gains. Such win-win solutions were mentioned
23 earlier, in Section 4, in connection with the empirical estimates of the MAC curves (e.g. Figure
24 4.2): these "below-the-line" options in the MAC curves are equivalent to the options in quadrant
25 III of a multi-attribute analysis.⁷⁵

26 Finally one should note that MCA leads to *implicit* valuations whenever two options are
27 compared. For example, in the case of Figure 5.4, a decision-maker who prefers option "Y"
28 ("max hydro+no coal") to point "X" ("NoCoal+lowSoil") makes an implicit valuation of the
29 concomitant reduction of GHG emissions in terms of the increased costs (i.e. equal to the slope
30 of the trade-off curve between X and Y, about 200\$/ton of CO₂).⁷⁶

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⁷³ We note also that the trade-off analysis and surfaces will be much more complex as the
number of attributes increases.

⁷⁴ Decision analysis distinguishes among several types of dominance -- such as strict
dominance and significant dominance -- see e.g. Meier and Munasinghe (1994) for an application of
these concepts to environmental decision-making.

⁷⁵ In general, of course, the trade-off curve may extend into quadrant II, and quadrant III may
contain fewer, or need not contain any solutions at all.

⁷⁶ However, because of the presence of joint products -- each represented by a different
dimension in the multi-dimensional trade-off space -- such valuations that look only at two
dimensions need to be interpreted with some caution.

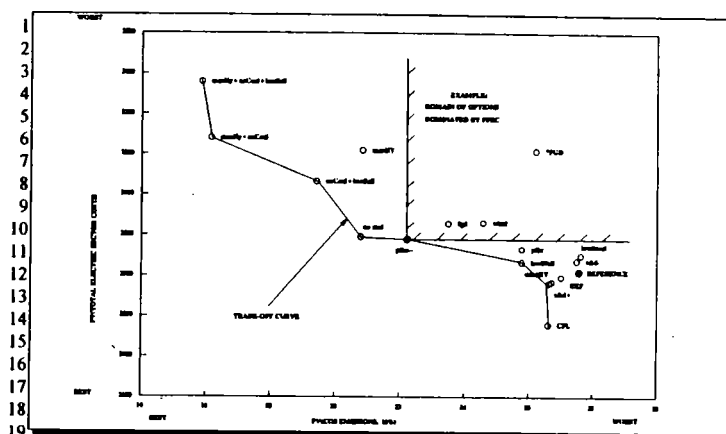


Figure 5.3: The trade-off curve

source: Meier, Munasinghe and Siyambalapitiya (1993)

Table 5.4: Technology interventions for GHG emission reductions

option	comments	symbol
wind energy	305 Mw total	wind
mini-hydro		minihy
DSM: energy efficient refrigerators		EEF
DSM: compact fluorescents		CFL
T&D loss reduction	10% T&D loss goal (in place of 12%) by 2000. 12% goal delayed to 2003	TD+
max hydro	builds both reservoirs in the Upper Kotmale project, 144Mw high dam version of Kukule	maxHy
clean coal technology	pressurized fluidized bed combustion-combined cycle units; assumed for all coal units after 2000;	PFBC
	with pessimistic capital cost assumptions	PFBC-
clean fuels	use imported low-sulfur residual oil for diesels (0.5% S by weight rather than 2.5% S)	low S oil
	use low sulfur (0.5%) coal (rather than 1% S coal)	low S coal
FGD systems	model free to choose optimal generation mix; coal plants must have FGD systems.	FGD
	FGD systems forced onto basecase solution	**FGD
no coal	model free to choose least-cost combination of diesels + hydro	noCoal

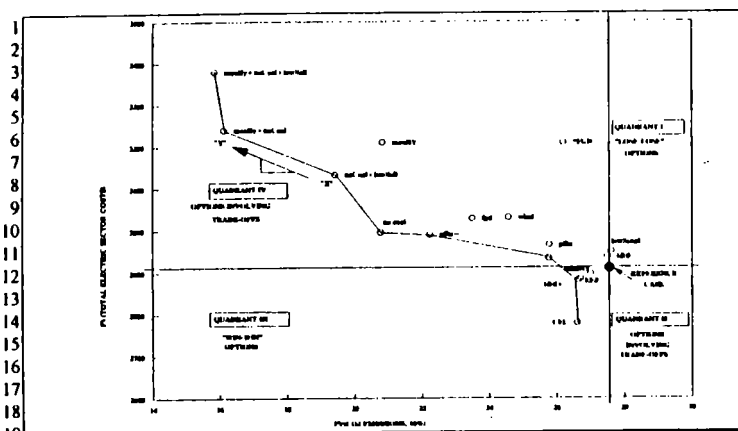


Figure 5.4: "Win-win" options
source: Meier, Munasinghe and Siyambalapitiya (1993)

1 Concluding Remarks

Cost-benefit analysis has many advocates but also many detractors. Certainly the rather narrowly defined, traditional approaches to CBA, developed originally for project level decision-making with planning horizons typically no more than 20 years, clearly have difficulty in dealing with the very long time frames, and high levels of uncertainty, encountered in the climate change. However, a family of techniques used in decision analysis, that are associated with a more broadly defined CBA approach provides a more promising basis for analyzing climate change issues.

In the introduction we noted that there were four essential questions facing decision-makers regarding climate change: (1) by how much should emissions of GHGs be reduced?; (2) when should emissions be reduced; (3) by what method should emissions be reduced?; and (4) who should reduce emissions?

The first question is answerable by CBA provided costs and benefits could be estimated with adequate accuracy -- the measures whose marginal costs are less than the marginal damage costs should be implemented. Clearly, it matters what perspective is taken the result will be different if restricted to a consideration of national costs and benefits than if the perspective is global. It is a fundamental result of CBA that the global perspective is the proper one.

The second question is a more complicated one, because it involves judgments about uncertainty. If the marginal damage (benefit) cost were known with certainty, or if future technological advances that might significantly change the marginal cost curve were known with certainty, then the timing of abatement is given by that portfolio of implementation options that maximizes the (deterministic) present value of avoided damage costs (benefits) less abatement costs -- a relatively straight forward calculation. But since neither damages nor costs are known with certainty (for example, if fusion technology were to be commercially available at a cost comparable to fossil-fueled technology by 2020 then the optimal timing and structure of abatement actions looks very different than if the date were 2070), extensions of CBA -- such as decision analysis -- are required. As indicated in Section 4 (see e.g. Box 2), recent developments have begun to deal with the question of timing, particularly with respect to the balance between R&D (on both the cost and benefit side) vis-a-vis immediate commitments to emission abatements.

The third question is closely related to the first. As we have seen (for example in Figure 4.2), most attempts to answer question 1 necessarily require consideration of the specific methods that might be used to reduce emissions. A bottom-up, empirical estimation of the marginal cost curve involves analysis of the broad spectrum of possible abatement options, from which marginal cost curves can be derived. Top-down models, typically using national or regional general equilibrium models (recall the results of Figure 4.4), also necessarily require explicit consideration of specific policy or technology options.

CBA cannot itself resolve the fourth question -- which involves equity -- but it does provide a framework for understanding the trade-offs to be made between equity and economic efficiency. CBA, when applied globally, can identify in which countries abatement costs are lowest, since the global perspective identifies all measures whose marginal costs are less than the global marginal benefits (recall Figures 4.5 and 4.6). But how such a program can be implemented in practice involves putting in place appropriate transfer payment mechanisms, the amount and structure of which is a matter of equity.

Nevertheless, despite its many imperfections, CBA (broadly defined) remains the best guide to policy-making for dealing with the essential questions that must be faced in dealing with climate change. The CBA approach forces decision makers to compare the consequences of

1 alternative actions, including that of no action, on a quantitative basis. -- and can certainly
2 make a contribution to resolution of the first three of these questions. To the extent that some
3 impacts and measures cannot be valued monetarily (like biodiversity), extensions of the
4 traditional CBA approach, such as multi-criteria analysis, permit quantitative expression of the
5 trade-offs to be made.

6 Finally, one should emphasize that the most important benefit of applying CBA is not
7 necessarily the predicted outcome (which is always dependent upon assumptions and the
8 particular technique that is used), but the *process itself*, which forces an approach to
9 decision-making that is based on rigorous and quantitative reasoning

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The Social Costs of Climate Change: Greenhouse Damage and The Benefits of Control

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Contents

Technical Summary

6.1 Conceptual Framework

- 6.1.1 Purpose of the Chapter
- 6.1.2 The Nature of Damage Assessment
- 6.1.3 The Valuation of Market and Non-Market Impacts
- 6.1.4 Transient and Equilibrium Warming
- 6.1.5 Time Horizon and Discounting
- 6.1.6 Technological Change
- 6.1.7 Adaptation
- 6.1.8 Recent Scientific Evidence

6.2 Damage Estimates for Benchmark Warming ($2\times\text{CO}_2$)

- 6.2.1 Agriculture
- 6.2.2 Sea Level Rise
- 6.2.3 Forests
- 6.2.4 Water Supply
- 6.2.5 Space Cooling and Heating
- 6.2.6 Insurance
- 6.2.7 Other Market Sectors
- 6.2.8 Health
- 6.2.9 Air Pollution
- 6.2.10 Water Pollution
- 6.2.11 Migration
- 6.2.12 Human Amenity
- 6.2.13 Ecosystem and Biodiversity Loss
- 6.2.14 Extreme Weather Events
- 6.2.15 Damage Estimates: Summary

6.3 Damage Estimates for Longer Term Warming

6.4 Catastrophic Risks

6.5 Regional Implications of Global Warming Damage

- 6.5.1 Regional Damage Estimates
- 6.5.2 Japan
- 6.5.3 Africa
- 6.5.4 Bangladesh
- 6.5.5 India
- 6.5.6 Indonesia
- 6.5.7 Malaysia

6.5.8	Thailand
6.5.9	Latin America
6.5.10	Small Island States
6.5.11	Conclusions on Regional Impacts
6.6	From Greenhouse Damages to Abatement Benefits
6.7	The Secondary Benefits of Abatement Strategies
6.8	Summary and Conclusions
Boxes	
Box 6.1	Attributing a Monetary Value to a Statistical Life
Box 6.2	Damage Aggregation Across Countries and Individuals
Box 6.3	Relative Damage in Developing and Industrialised Countries
Box 6.4	Valuation of Electricity Related Externalities in California
Figures	
Fig 6.1	Climate Change, Cost-Benefit Analysis and Sustainable Development
Fig 6.2	2xCO ₂ Damage vs. Abatement Benefits
Tables	
Tab 6.1	Overview on Climate Change Impacts
Tab 6.2	Preference Valuation for Endangered Species and Prized Habitats
Tab 6.3	Reported Fatalities due to Weather Events 1989-1992
Tab 6.4	Economic Damages from Global Warming: Present US Economy
Tab 6.5	Quantitative 2xCO ₂ Damages in Different World Regions
Tab 6.6	Monetary 2xCO ₂ Damage in Different World Regions
Tab 6.7	Expert Opinion on Climate Change Damage
Tab 6.8	Illustrative Damages from Long Term Warming: Present US Economy
Tab 6.9	Losses of Rice Output due to Sea Level Rise in Coastal Zones of Bangladesh
Tab 6.10	Vulnerability Index for Different Categories of Countries
Tab 6.11	The Social Costs of CO ₂ Emissions in Different Decades
Tab 6.12	Reduced Air Emissions due to CO ₂ Abatement
Tab 6.13	The Social Costs of Air Pollution

1 Technical Summary

2
3 This chapter is concerned with a socio-economic assessment of climate change impacts. Such
4 global warming damage estimates are an important input to benefit-cost analysis and other
5 decision making tools.

6
7 The benefit-cost approach requires that the damages from climate change be represented, as far
8 as possible, in terms of money units reflecting human preferences. To the extent that this is
9 possible the chapter expresses impacts in these terms, that is human preferences are expressed
10 by people's willingness to pay (WTP) to secure a benefit or their willingness to accept
11 compensation (WTAC) for a cost. Many of the impacts of climate change will not be revealed
12 directly in the market place - the so called non-market impacts. In these cases WTP and/or
13 WTAC are measured through 'surrogate markets' or 'created markets'. Surrogate markets are
14 real markets in which environmental change has an influence: a house price or land value may
15 be higher because of an environmental amenity for example. Created markets reflect people's
16 responses to questions put to them about their willingness to pay.

17
18 Most damage estimates are for equilibrium global warming associated with a doubling of
19 preindustrial CO₂-equivalent concentration of all greenhouse gases. Global damage is estimated
20 at 1.5% - 2.5% of world GNP for 2xCO₂ concentrations and equilibrium climate change. This
21 is to be interpreted as follows: if 2xCO₂ occurred now, it would impose this much damage on
22 the world economy now. Particularly vulnerable sectors include agriculture, the coastal zones,
23 human mortality and natural ecosystems. The chapter stresses the uncertain character of these
24 estimates. The possibility of catastrophes (low probability-high impact events) and surprises
25 cannot be ignored.

26
27 The regional variation in damage is substantial. Central estimates of the damage in different
28 developing regions range from a minimum of 2% of national GNP to a maximum of 9% of GNP
29 for 2xCO₂. For individual nations the figure could be even higher. Small islands states and low
30 lying coastal areas are especially vulnerable. Most impact work is confined to developed nations,
31 however. The confidence in estimates for developing countries is much lower.

32
33 The chapter emphasises the need for a long term perspective reaching beyond 2xCO₂, even
34 though socio-economic forecasts over more than a century are highly uncertain. Most models
35 assume a non-linear (convex) damage-temperature relationship, resulting in damages of 6% or
36 higher for 10°C warming. These figures are illustrative only.

37
38 2xCO₂ damage estimates usually form the basis for the calculation of marginal damage, i.e. the
39 extra damage done by one extra tonne of carbon emitted. Marginal damage is estimated at \$ 5-
40 25 per tonne of carbon, although some estimates range up to \$125 per tonne of carbon. This
41 wide range reflects variations in scenarios, models, discount rates etc of the current generation
42 of models. These models are simplistic and are poor representations of dynamic processes. The
43 effect of climate change adaptation in particular is poorly understood.

1 Marginal global warming damage is equal to the marginal global warming benefits of emission
2 control. However, the benefits of greenhouse gas abatement will not be limited to reduced
3 climate change costs alone. A reduction in CO₂ emissions will often also reduce other
4 environmental problems related to the combustion of fossil fuels. The size of these so called
5 secondary benefits is strongly site dependent. Studies for Norway, the UK and some other
6 countries indicate that the benefits of reduced air pollution could offset between 30% and 100%
7 of abatement costs.

1 6.1 Conceptual Framework

2 6.1.1 Purpose of the Chapter

3 This chapter is concerned with the nature of the damage from climate change. Damages here
4 refer to the consequences of these effects for *individual and social welfare* from an economic
5 point of view. The chapter assesses the possible aggregate scale, the geographical distribution,
6 and the nature of those damages. It raises some issues relating to decision-making rules since
7 alternative ethical approaches to harm done to future generations have implications for damage
8 assessment (see also Chapter 5).

9 6.1.2 The Nature of Damage Assessment

10 Two broad perspectives have emerged on ways to analyse decisions which have adverse effects
11 on generations yet to be born: the benefit-cost framework and the sustainability framework.
12 While they initially appear to be very divergent, they have features in common.

13 The *benefit-cost framework*. It requires that the future damages be weighed up, integrated into
14 an overall assessment, and then compared to the costs of measures undertaken now by the
15 current generation. In turn, there are two perspectives on the way in which benefits and costs
16 should be compared:

- 17 (i) the *judgemental benefit-cost* framework, in which gains and losses are compared but
18 without reducing them to common units. On this approach, the monetary costs of control
19 might be compared with some wide-ranging *environmental impact statement* representing
20 the best state of knowledge about climate change impacts, together with assessments of
21 the *distributional incidence* of those impacts both geographically and across time;
22 (ii) the *monetised benefit-cost* framework. On this approach, the common unit of money is
23 used to 'reduce' the benefits of climate control to the same units as costs to permit direct
24 comparison, but only as far as 'monetisation' is credible.

25 Approach (i), which often reduces to multi-criteria analysis, is discussed in Chapter 5 (see also
26 the discussion on integrated assessment in Chapter 10).

27 Approach (ii) is characterised by the following features:

- 28 (a) benefits and costs are defined in terms of human preferences (see Chapter 2 for a
29 discussion on anthropocentrism). A benefit is anything that improves an individual's
30 wellbeing; a cost is anything that reduces that wellbeing;
31 (b) those preferences are expressed in the market place by willingness to pay (WTP) for a
32 benefit and willingness to accept compensation (WTAC) for a cost (for a comparison of
33 the two concepts, see eg Shogren *et al*, 1994);
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- (c) where markets do not exist - for example with respect to ecosystem change - WTP and/or WTAC are measured through 'surrogate markets' or 'created markets'. Surrogate markets are real markets in which environmental change has an influence: a house price or land value may be higher because of an environmental amenity for example (the hedonic property price method). Created markets reflect people's responses to questions put to them about their willingness to pay (the contingent valuation method). Although controversial, these approaches are well established in the literature (for an introduction and assessment, see eg Carson *et al.*, 1994; or Braden and Kolstad, 1991).
- (d) the 'intrinsic' values of other species and ecological systems may be captured at least in part by created markets since people may be expressing their understanding of intrinsic values when they express their willingness to pay for the continued existence of an environmental asset even though they may make no use of it, nor do they intend to use it ('passive use', or 'existence' value - see Carson *et al.* 1994);
- (e) future generations' preferences count at least in so far as they are assumed to want what current generations want. If there is evidence that they will want more environmental assets affected by climate change, then this 'rising relative preference' can be accommodated by benefit-cost approaches by allowing benefits or cost to rise through time;
- (f) future generations' preferences may count equally with current generation preferences if the *pure time preference* component of the *discount rate* is zero. If it is positive, their preferences count less in the benefit cost framework. The discount rate may also depend on the rate of economic growth, which in turn depends on emission abatement as well as climate change: The discount rate becomes endogenous (see Chapter 4);
- (g) since WTP is constrained by income, it is likely to be less for low income groups than for high income groups. This may appear to give rise to an unfairness since the preferences of low income groups (countries) will carry less weight than the preferences of high income groups. One way to address these ethical issues is to give different weights to different income groups in the aggregation process (see Box 6.2). Another way might be to adopt the valuations of the higher income groups and apply them to all countries (eg Hohmeyer and Gärtner, 1992. See also Box 6.1).
- (h) aggregation of damages is also a hallmark of benefit-cost studies. Care has to be taken in interpreting such aggregate figures since they clearly mask (a) substantial regional variations in impact within a country and between countries, and (b) dislocation costs in adapting to changed local impacts. The aggregation of sectoral impacts also tends to imply that losses in one sector are compensated for by gains in other sectors;
- (i) benefit-cost studies can promote research aimed at reducing the emissions of greenhouse gases and the impacts of climatic change.

The second overall perspective - the *sustainability approach* (e.g. Howarth and Monahan, 1992; Spash, 1994) - gives the highest priority to the avoidance of 'unacceptable' damage to future generations. Rationales for avoiding this harm sequence:

- (a) there is reasonable evidence to suppose that actions now in emitting greenhouse gases could cause significant damage to future generations, including unborn generations;
- (b) future generations are defenceless against actions taken now in the knowledge that those actions may cause harm;
- (c) current generations have obligations to future generations at the very least through a set of links from parents to children, from children to their children, and so on (Howarth, 1992), or, more generally, because future generations have rights even when those generations are not identifiable, and even when their existence is contingent on actions taken now;
- (d) probable improvements in the wellbeing of future generations cannot be treated as 'compensation' for harm knowingly inflicted on future generations by current generations, any more than harming the poor now can be excused by paying them compensation after the event (Spash, 1994);
- (e) hence doing harm is not reversible by doing good. Benefits and costs cannot be 'traded off' in the sense advocated by benefit-cost analysis *regardless of whether the benefit-cost analysis is monetised or not*. There is a *duty* to avoid future harm.

As with the benefit-cost approaches, all the propositions in the sustainability approach are open to dispute. Controversial assumptions include: (i) that harm can accrue to individuals whose existence is contingent on actions now and (ii) that trade-offs can be avoided, since any action now incurs a cost of abatement, and any abatement cost involves losses for others which in turn implies that other individuals' rights may be impaired.

Within the sustainability approach two views are (see Figure 6.1):

- (i) that since the obligation to avoid harm is absolute, the cost of avoiding harm is irrelevant: the benefits of control are so large that inspection of costs is unhelpful. This is the *absolute standards* approach;
- (ii) that harm should be avoided subject to a constraint that avoiding harm does not itself impose 'unacceptable cost' - the *safe minimum standards* approach.

The sustainability approach takes a long-term view and stresses the need to sustain a viable global ecological system. It therefore tends to be characterised by:

- (a) the avoidance of unacceptable risk where risks are known;

- (b) the 'precautionary principle' - whereby actions giving rise to *possible* but quantitatively unknown but potentially very large risks are avoided or corrected;
- (c) the view that what is unacceptable is only partly measured by reference to individuals' preferences since (i) individuals are not well informed about climatic risks, (ii) experts are similarly not well informed due to uncertainty about climate change and its effects, and (iii) human preferences may not capture other values, e.g. intrinsic values;
- (d) very low discount rates of the order of a few percentage points, and maybe even zero.

Whereas the benefit - cost approach seeks to measure the scale of damage, the sustainability approach assumes that damage will be 'significant', so much so that action is warranted regardless of quantification.

The sustainability approach often tends to have as its objective a concern to avoid exceeding some target rate of temperature rise, often quoted as 0.1°C per decade, and some absolute overall rise in temperature of 2-3°C. Examples include Krause *et al.* (1989) and Rijsberman and Swart (1990). The costs of achieving these constraints are assumed to be worth incurring in order to avoid the risks to future generations.

With reference to the benefit-cost approach, it is well known that a time path in which the present value (i.e. the discounted value) of benefits minus costs is maximised need not be a sustainable path, and that a sustainable path could, in turn, be unacceptable in terms of its implied living standards for each generation (Page, 1977; Pearce *et al.*, 1994; Pezzey, 1994). The choice between benefit-cost approaches and sustainability approaches therefore depends crucially on (a) attitudes to uncertainty, (b) the degree of concern for the wellbeing of future generations, and (c) beliefs about the damage function, i.e. the way in which warming relates to damages.

A consensus viewpoint stresses the following common features of both the sustainability and the benefit-cost approaches:

- (a) the existence of uncertainty cannot justify 'business as usual', i.e. doing nothing. Action on climate change is justified since the damage costs could be very high, the 'coefficient of concern' for the future is not zero, and there are costs of delayed action since greenhouse gas impacts may not be reversible;
- (b) the right benefit-cost perspective is one which investigates the benefits and costs of taking actions. Such actions are likely to yield benefits of a similar order of magnitude as the costs of the actions for some time to come, since avoided climatic damages are not the only benefits of those actions. This underlines the difference between *damage estimation* and *abatement* benefits: the latter include the avoided damages estimated by the former concern, but also include other benefits from greenhouse gas abatement (see Section 6.7);

- (c) neither sustainability nor 'maximising net benefits' is an obviously non-controversial objective. Sustainability cannot be an overriding objective independently of the quality of life that is sustained or the costs of achieving it. Maximising net benefits cannot be an overriding objective since it may be consistent with an approach which discriminates against future generations. This suggests an approach in which the best features of both approaches are taken: a concern for the wellbeing of future generations, the wellbeing of Earth itself, and acknowledgement of the limited resources that all societies have at their disposal to tackle global problems. Such approaches come closest to the 'safe minimum standards' approach: taking a precautionary approach in favour of the environment unless the demonstrated costs of so doing are very high. Precaution would have its justification in very high damage costs: damage costs must therefore be investigated. The acceptability of control costs is dealt with in Chapters 8 and 9.

6.1.3 The Valuation of Market and Non-Market Impacts

The benefit-cost approach requires that the damages from climate change be expressed, as far as is possible, in terms of money units reflecting human preferences. Many of the impacts of climate change will not be revealed directly in the market place - the so called non-market impacts. The absence of markets does not mean that non-market impacts are any less important than market impacts. The point is to ensure that non-market impacts are adequately accounted for.

Non-market impacts may take a variety of forms. One important example is the impact of warming on human health. Human health is, generally, publicly provided without full charge. In some cases, there are surrogate markets for risks to life. Occupations are subject to varying degrees of risk of accident and ill-health and that risk is sometimes compensated for by variations in wages. The 'risk premium' in the wage can then be interpreted as a valuation of the risk (see Box 6.1). Valuation of morbidity is more complex: contingent valuation approaches are best suited to such indicators but, as yet, few studies exist outside the USA. In their absence, second best measures such as the costs of treatment tend to be used.

The general approach in benefit-cost studies is to treat market and non-market impacts on the same footing. Non-market costs can be high, between 30% and 80% of the total. Tol (1994a) suggests that the way non-market impacts are treated matters, however. The reasons are: (a) they affect human wellbeing directly (through the utility function), rather than through production, (b) they are liable to be less substitutable and (c) their value will rise relative to other (production) damages.

Market price (in the case of market goods) and elicited WTP (for non-market goods) reflect people's appreciation for the *marginal* (last) unit of a good or service consumed. The utility gained from consuming the first unit of a good is usually much higher than that from consuming the last unit, however. Especially for food and other products with price inelastic demand - where the appreciation of additional units beyond an essential minimum decreases rapidly - the value lost from a cutback in availability will be understated if the quantity loss is evaluated at

the original (ex ante) price. Price increases as a consequence of global warming then become important. The correct measure to assess the costs of global warming in such cases is the change in producer and consumer surplus. Consumer surplus is the excess of what consumers would be willing to pay if necessary above what they actually pay. Producer surplus is what producers receive in excess of their actual costs of production. This consideration also means that it can be misleading to gauge the potential impact of global warming by the present size of a sector in the economy. In industrial countries agriculture is typically on the order of 3 percent of GDP, but reduction of X percent in agricultural output could cause far more than 0.03X percent of GDP economic loss because of the induced price increase and loss of consumer surplus.

6.1.4 Transient and Equilibrium Warming

The time dimension of damage, and the difference between transient and equilibrium warming are also important. Ocean thermal lag causes realized equilibrium warming from a given steady-state increase in greenhouse gas concentrations and their consequential radiative forcing to be delayed by at least two, and perhaps several, decades¹. Among economic analyses, Cline (1992a) simply applies a 25 year lag, whereas other models (e.g. Nordhaus, 1994b) often explicitly model thermal capacities of, and transfer between the atmosphere, upper ocean and lower ocean (see Chapter 10). The lag of realized warming introduces an inherent asymmetry into the economics of global warming: advantages associated with emissions (e.g. the benefits of automobile driving or electricity generation) occur immediately, whereas economic damages occur only after a significant lag.

In addition, an even more fundamental asymmetry is that emissions in a given year typically generate a contemporary, one-year flow of advantages, but create a stock of warming that then produces a recurrent annual flow of damages into the indefinite future. There is thus an inherent temporal asymmetry between earlier satisfaction from emissions and later, more persistent damages, even if thermal lag is ignored.

For a specified radiative forcing, the transient warming may not follow a smooth path between present and future equilibrium climate. Transient climate change in a particular region cannot therefore be assumed to be a steadily rising fraction of equilibrium impact; instead, there could be discontinuities and reversals. Damages is likely to be sensitive to such variability. Adjustments of natural systems and social institutions are not instantaneous. A world with continual climate shocks would affect the ability of economic and natural systems to adjust and to recover. The economic implication is that the strategy of relying solely on adaptation rather than abatement could have higher costs than implied under a smooth transient path.

In addition, it is generally agreed that the faster warming occurs - either because of higher

¹ Under business-as-usual conditions of steadily rising concentrations, realized warming at a point in time is roughly 60% of equilibrium or committed warming corresponding to radiative forcing already present, for atmospheric models with climate sensitivity parameters of 4°C; and 80%, for 1.5°C (IPCC, 1990a).

climate sensitivity (equilibrium warming for a given radiative forcing) or a shorter ocean thermal lag - the greater the economic damages will be. That is, damage is a function of absolute warming as well as the rate of warming. Species and forests will have less time for migration; agricultural and other climate-sensitive human activities will have less time for adaptation. In a survey of experts' opinions Nordhaus (1994a) finds that for a hypothesized warming of 6°C, the mean estimate of damage is 6.7% of world product if the arrival date is 2175, but 10.4% if the warming occurs by 2090 (with wide extremes around the mean in both cases, see Table 6.7 below).

The issue of transient climate change is further discussed in Chapter 10 on integrated assessment.

6.1.5 Time Horizon and Discounting

Given the long time horizon of the global warming problem the question of discounting is crucial for the valuation of climate change impacts. Unfortunately, there is no agreement on the "correct" discount rate and different rates have been used in applied studies so far (see Chapter 4 for details). In a benefit-cost analysis of greenhouse abatement, Cline (1992a) adopts a zero rate of pure time preference (ρ), and sets the social rate of time preference (SRTTP) at 1.5% per annum, the result of an assumed consumption growth rate of 1% multiplied by an elasticity of marginal utility of 1.5. After taking account of the share of resources coming out of capital (20% economy-wide, versus 80% out of consumption) and shadow-pricing capital effects (at a price close to two units of consumption equivalent to one unit of capital), Cline's effective discount rate is in the range of 2% per annum. In contrast, most global warming optimization models (e.g. Nordhaus, 1994b; Peck and Teisberg, 1992; Manne *et al.*, 1993) apply a pure rate of time preference of 3%. They typically also use a logarithmic utility function, which, for a per capita growth rate of 1-2%, implicitly adds another 1-2% for utility-based discounting, to give a SRTTP of 4-5%. The divergent discounting methods explain much of the difference in the policy findings of different studies.

6.1.6 Technological Change

Even over two or three decades, technological change can profoundly alter the options available for low cost adaptation, on the one hand, or for greenhouse abatement, on the other. Over a time horizon of two or three centuries the technological unknowns become overwhelming. Cline (1992a) suggests that this problem can be obviated if it is assumed that the proportional effects of technological change are the same for abatement costs as for the benefits of limiting warming. Thus, whereas technological breakthroughs on seed varieties might neutralize damage from increased droughts, thereby reducing the benefit of limiting warming, breakthroughs in non-fossil-fuel (e.g. solar) energy could correspondingly reduce the opportunity cost of reducing carbon emissions. The assumption that unanticipated technological changes are distributed evenly on both sides of the benefit-cost calculus provides a logical basis for proceeding with the benefit-cost analysis of abatement applying the best expectations of technologies on both sides. However, the powerful influence of technological change means that there is a wide band of

uncertainty around the comparisons from this standpoint, added to that already present from climate uncertainty.

Policy also affects technological change. Especially over a time horizon of many decades, new technology will respond to price and non-price signals sent by policy. Thus, the future path of energy supply technologies is likely to hold a wider array of low-carbon alternatives, if there is a price signal discouraging carbon emissions.

6.1.7 Adaptation

The severity of global warming impacts will depend on people's ability to adapt to a warmer world. Measures will generally be taken to accommodate to global warming, both on an individual level and by society as a whole. The search for more resilient crops will be intensified, vulnerable coastlines will be defended by sea walls, improved weather forecasts will help to better prepare for extreme weather events. On an individual level farmers will change crops or adjust planting dates. Households will increase their demand for air conditioning, people may migrate to less affected regions, and so on. See Chapter 7 and IPCC Working Group 2, Second Assessment Report, for a further discussion on adaptation.

However, the degree of adaptation in developing countries is likely to be far less than in developed countries due to (a) lack of financial resources and (b) lack of institutional capacity. Where it is feasible, adaptation can potentially be a very powerful option. In a stylized cost-benefit model of global warming policies, Hope *et al.* (1993) found strongly positive cost-benefit ratios for an "aggressive adaptive policy" in Europe, mainly in the form of coastal protection. The benefits of adaptation exceed the costs by more than a factor 20. Fankhauser (1994a) calculates optimal coastal protection levels of 50 to 100% for the countries of the OECD. In a series of country studies IPCC (1994) found that through appropriate adaptation measures the number of people at risk from flooding could on average be reduced by about a factor 8.

Agricultural studies provide a similar picture. In a case study of the Missouri-Iowa-Nebraska-Kansas (MINK) region, Easterling *et al.* (1993) found that low-cost adaptation measures, like earlier planting or increased irrigation, could succeed in reducing agricultural damages to the region by 30% or more (see also section 6.2.1). A comparable range was found by Rosenzweig *et al.* (1993) and (using the same yield data) Reilly *et al.* (1994). In the Rosenzweig *et al.* study a change of -1.2 to -7.6% in worldwide cereal production without adaptation is reduced to 0% to -5% with moderate farm-level adaptation and +1% to -2.5% with a more comprehensive managerial adjustment. As a consequence, the global welfare loss reduces from \$ -0.1 to -61.2 billion without adaptation to \$ +7.0 to -37.6 billion in the case of a moderate response (Reilly *et al.*, 1994).

Adaptation will in general not be costless, and may require extensive planning. The need for an integrated and forward looking coastal zone management has been identified as an essential prerequisite for the future development of coastal zones (IPCC, 1994). The significance of adaptation will also depend on institutional factors. Limited availability of irrigation water or of

sufficient capital to finance increased input requirements (e.g. more fertilizer) may limit the scope of agricultural adaptation in poorer regions (Rosenzweig *et al.*, 1993).

Conceptually, the costs of global warming impacts in the presence of costly adaptation consist of two parts: The costs of adaptation (e.g. for coastal protection), plus the costs of the remaining, unmitigated damage (e.g. the loss of unprotected land). In the estimates reviewed in section 6.2, for many categories the damages of global warming also incorporate considerations of adaptation. A prime exception is loss of biodiversity, for which there are few adaptation options. Damage from sea level rise is partly comprised of the cost of building coastal protection structures. Similarly, the impacts on the electricity sector caused by global warming amount to costs required or induced by adaptation (space cooling). Implicitly or explicitly most of the estimates incorporate both effects: costs of plausible adaptation, plus the remaining damages from unmitigated impacts.

The question of the optimal level of adaptation is strongly linked to that of optimal mitigation. The most desirable level of adaptation will depend on the amount of greenhouse gas abatement undertaken, and *vice versa*. Abatement and adaptation policies should therefore be carefully coordinated. For example, if significant abatement can be achieved at reasonably low costs, less action may be needed with respect to adaptation. Conversely, if the consequences of global warming could easily and cheaply be accommodated by adaptation, there would be less need for preventive carbon abatement.

However, as suggested by the hybrid nature of most of the estimates, as *damage-cum-adaptation* costs, assuming a strict dichotomy between abatement and adaptation would be misleading. Indeed, an underlying point is that the greenhouse problem is likely to require both sets of actions. Even with the most ambitious abatement policy, benchmark 2xCO₂ warming seems likely to occur eventually, although the date can be greatly delayed. Conversely, even the most extensive adaptation strategy is unlikely to fully mitigate the adverse impacts of global warming. Adaptation is primarily a complement, not an alternative to greenhouse gas abatement.

6.1.8 Recent Scientific Evidence

The literature reviewed below largely takes as its point of departure the scientific appraisal of IPCC (1990a). It is important to consider whether changes in the scientific assessment since then provide grounds for altering the economic evaluation of the greenhouse effect. In the 1995 review, IPCC Working Group I (scientific assessment) has identified the following changes in the underlying impact science that might affect the measurement of damage.

First, while the climate sensitivity parameter range remains at 1.5-4.5°C for equilibrium 2xCO₂, transient realised global mean surface temperature is now expected to rise by a central estimate of roughly 0.25°C/decade, or by 2.5°C by 2090 over the 1990 base. The corresponding central estimate in the 1990 report was 0.3°C/decade, for a cumulative 4.2°C over the preindustrial base by the year 2100. This diminution is attributable to consideration of terrestrial uptake, incorporation of the effect of ozone stripping in the evaluation of radiative forcing from CFCs,

and the influence of aerosol sulphates.

Second, there is increasing emphasis on regional differences. These stem importantly from the differential impact of ocean thermal lag. In the Northern Hemisphere, with greater land mass relative to oceans, realized warming may be 0.5°C/decade, twice the pace of the global mean. Centres of land masses may have warming two to three times the global mean. Of specific interest for social cost estimates is the effect of increasing land-ocean temperature differentials.

Third, a central estimate for sea level rise by the year 2100 is now placed at 45 cm, compared to 66 cm in IPCC (1990a).

The broad thrust of these changes is to moderate the expected pace of mean global warming, but to intensify the role of variability and surprises at the regional level. For mid-continental areas in the Northern Hemisphere, the new estimates would seem to leave even the mean pace of warming close to that in the earlier report of IPCC (1990a). Increasing ocean-land differentials suggest greater precipitation changes and higher storm damages. Importantly, the new incorporation of aerosol sulphates also carries the implication of potential acceleration from baseline warming if there is greater progress than expected in the reduction of urban pollution and thus reduction in these aerosols (Wigley and Raper, 1992).

In view of these considerations, it would seem that increased damage associated with variability and unpredictability, as well as greater attention to the high regional warming coefficients for the Northern Hemisphere and for mid-continental areas, would broadly compensate reduced damages from the standpoint of the timetable of mean warming. This would mean that the time path for mean global warming over the next century would only be reduced by 17% (from 0.3°C/decade to 0.25°C/decade). On this basis, there would appear to be little reason for altering the broad orders of magnitude of the damage estimates in the economic effects literature reviewed below. At the most, the revised assessment might imply somewhat later damages for the Southern Hemisphere (and thus, broadly, for developing countries).

6.2 Damage Estimates for Benchmark Warming (2xCO₂)

Monetary values for climate change damages have been estimated for a number of sectors in the market economy. In addition, there are non-market damages, which are typically more difficult to quantify (e.g. species loss), and a mixture of both market and non-market effects in some sectors (e.g. forest loss in lumber and public use value). Table 6.1 provides an overview of the categories of damages that might be caused by climate change and associated sea level rise. The estimated damages are not complete. For some categories, monetary estimates of damages have not been attempted. For other categories, the estimated damages only partially reflect the potential welfare loss. In many cases, the preferred measure of welfare impacts - willingness to pay - is approximated by other indicators. Estimates are predominantly for the United States and other OECD countries. Material relating to other countries is sparse although increasing. The incomplete nature of the damage estimates presented here must be borne in mind when

evaluating the full welfare implications of global warming. Finally, all the estimates are subject to uncertainty. Where possible, ranges of values are indicated.

[Table 6.1]

Neither current damages, i.e. those associated with the concentration rise from 280 to 350 ppm, nor long-run climate change impacts have gained much attention in the literature so far. Instead, most estimates are for equilibrium global warming associated with a doubling of pre-industrial carbon dioxide equivalent concentration of all greenhouse gases (referred to here as benchmark warming). Absolute estimates are usually based on the present-day economy, and then expressed as a percentage of GDP. Projections then apply these percentage impacts to future world product (e.g. to 2060 for realized benchmark warming). Simply projecting percent losses to the future is a somewhat unsatisfactory approximation. Future impacts will depend on economic, demographic and environmental developments. Some of the effects are likely to grow more than proportionately with GDP (for example, the economic value of non-market goods) and others less than proportionately (for example, agriculture). Future demographic developments may change current vulnerability and migration patterns in an unknown way (for a discussion of possible futures see also Chapter 12).

6.2.1 Agriculture

Global warming is likely to damage agriculture in many areas but aid it in others. The principal damage will arise from heat stress and decreased soil moisture. Warmer temperatures cause the growing cycle of many plants to accelerate, allowing less time for plant development before maturity. Continental interiors are expected to become drier with global warming. The principal offsets would be longer growing seasons in cold Northern climates, and the fertilization effect of greater atmospheric carbon dioxide.

Rind *et al.* (1990) use GCM results to calculate that for many mid-latitude locations (e.g. the United States), the incidence of severe droughts that currently occur only 5% of the time would rise to a 50% frequency by the 2050s, based on the difference between precipitation and potential evapotranspiration (E_p). They find that:

E_p increases most where the temperature is highest, at low- to mid-latitudes, while precipitation increases most where the air is coolest and easiest to saturate by the additional moisture, at higher latitudes (p. 9983).

On the favourable side, higher atmospheric carbon concentrations are expected to increase photosynthesis, which combines carbon dioxide and water to produce carbohydrates. Laboratory experiments suggest that doubling of CO₂ from 330 to 660 ppm could raise yields by 34% for C₃ crops (wheat, rice, soybeans, fine grains, legumes, root crops, most trees) and 14% for C₄ crops (maize, sorghum; see Schneider and Rosenberg, 1989b). However, open-field conditions may not necessarily achieve the same yield increases (Parry, 1990; Evans *et al.*, 1991; Körner

and Arnone, 1992; Erickson, 1993). Bazzaz and Fajer (1992) note that the laboratory experiments are dependent on availability of fertilizer and water, and conclude that because of "competitive interference and limited nutrients ... we do not expect that agricultural yields will necessarily improve in a CO₂-rich future." Moreover, the doubling of atmospheric carbon is conceptually the wrong experiment for calculating the effects of benchmark (equilibrium) warming. After taking account of other greenhouse gases, the CO₂ concentration in the 2xCO₂-equivalent equilibrium would be only 440 ppm (Cline, 1992a, calculated from IPCC, 1990a).

In assessing agricultural damage on a global level, changes in trade flows are of crucial importance. Kane *et al.* (1992) apply the US Department of Agriculture's Static World Policy Simulation (SWOPSIM) model of agricultural trade to emphasize the importance of trade effects. Even in a "very adverse" scenario in which yields fall by 5% - 40% in most developed countries, the former Soviet Union and China, and remain unchanged in most other developing countries, net global welfare declines by only 0.47% of GDP. World food prices are expected to increase in the order of 40% or more, with repercussions on both producer and consumer welfare. In a food exporting country like the United States, for example, consumers are expected to lose \$40 billion annually in consumer surplus (at 1986 prices), while US farmers gain \$19 billion annually in producer surplus because price increases more than offset yield reductions. Of course, the implication is that a corresponding loss of consumer surplus occurs for importing nations, associated with terms of trade gains on US farm exports. The main loser identified in this particular model run is China, with economic losses of more than 5% of GDP. Increased world food prices also heavily affect consumers in the former Soviet Union. In a second, more optimistic scenario, worldwide impacts are practically zero, with negative results in Canada, Japan and Europe being offset by gains in Australia, and now also the former USSR and China. The Kane *et al.* figures, averaged over all scenarios, are reproduced as the agricultural damage in Table 6.5.

In another global study Rosenzweig *et al.* (1993) coordinated research applying crop simulation models in 18 countries to examine the impact of benchmark 2xCO₂-equivalent warming on yields for wheat, rice, maize, and soybeans by 2060. Linking the results in a world trade model (Basic Linked System), they calculated the impact on production levels, prices, and the number of people at risk from hunger. The study finds that crop yields would decline in the low latitudes, where they are currently grown near their limits of temperature tolerance. However, yields could increase at middle and high latitudes when carbon fertilization is included. In the case of moderate adaptation, output rises in developed countries by 4% - 14% but falls by 9% - 12% in developing countries (which must import). Depending on the GCM used, global output falls by 0% - 5%, prices rise by 10 - 100%, and the number of people at risk from hunger rises from a baseline of 640 million to a range of 680-940 million. Although the results are open to the critique that the climate models used (GISS, GFDL, UKMO) have sensitivity parameters higher than the IPCC's 2.5°C (Reilly and Hohmann, 1993), from another standpoint the results are optimistic. They employ a carbon concentration of 555 ppm, which is essentially a transient

concept for the year 2060, rather than an equilibrium concept for 2xCO₂-equivalent (440 ppm)².

The number of additional people suffering from hunger has also been estimated by Hohmeyer and Gärtner (1992). Their estimate of 900 million deaths over a 20 year period up to 2030 is based on a rather *ad hoc* line of reasoning, though. Their figure, which measures actual casualties, also appears rather high, compared to the more sophisticated Rosenzweig *et al.* (1992) estimates of people *at risk*.

On a regional level, a study for the European Union predicts that overall agricultural yields in Europe are likely to increase as result of increased temperature and precipitation. Welfare gains of ECU 3.2 billion are predicted for 1°C warming and 12.2 billion for 4°C (CRU/ERL, 1992). Gains would mainly occur in the north, while the outcome for southern Europe would be more mixed.

For the United States, Adams *et al.* (1993) estimate the combined economic effects of global warming on agricultural producers and consumers under different scenarios. Impacts are generally negative if based on the 2xCO₂ predictions of the UK Meteorological Office. Using the more benign GISS and GFDL forecasts yields mostly positive impacts, except for the cases without CO₂ fertilization: producer gains, particularly in the north, are generally large enough to offset the losses faced by consumers and producers in the south. In their "standard" scenario with a CO₂ concentration of 550 ppm and no trade and adaptation effects, the estimated agricultural impacts range from -\$18 billion (UKMO) to +\$10 billion (GISS). Substantial economic losses are predicted in all scenarios once temperatures rise by 4°C. Based on earlier estimates by US EPA (1989), Nordhaus (1991) and Cline (1992a) have estimated US damages of roughly zero and \$17.5 billion, respectively. The former estimate is based on a 660 ppm scenario, while Cline assumes 440 ppm, consistent with CO₂-equivalent doubling.

A study of the Missouri-Iowa-Nebraska-Kansas (MINK) area introduces the further influence of farmer adaptation (earlier planting, use of longer season varieties, changes in tillage to conserve water; see Easterling *et al.*, 1993; Rosenberg and Crosson, 1991a, b). Using actual climate conditions of the 1930s as an analogue for a 2030s climate, the study finds that without carbon fertilization climate change cuts agricultural production in the area by 17.1%, but only 12.1% with on-farm adaptations. Adaptation thus reduces losses by about one third. If 100 ppm carbon fertilization is added as an offsetting factor, output is reduced by only 8.4%. This loss is cut further to 3.3% by adding the influence of adaptation. Considering that regional temperatures were only about 1°C higher than today in the 1930s, and adjusting for commensurate carbon fertilization, the MINK results suggest losses on the order of 10% for benchmark 2xCO₂ warming, even with farmer adaptation.

² The eventual equilibrium warming consistent with the 2060 greenhouse gas concentrations would be higher than benchmark warming (because of the lag of two decades or more between committed and realized warming, associated with ocean thermal lag).

In another US study Mendelsohn *et al.* (1993) argue that the production function method commonly used in crop models inadequately captures induced producer responses. They suggest that existing cross-section data across different climatic regions can provide a better guide to total effects incorporating these responses. They use county-level US data to regress farmland values on climate and a number of other relevant variables. They simulate the impact on aggregate US agriculture of global warming causing a rise of 2.8°C (5°F) in mean temperature and 8% in rainfall. Under these assumptions, US agriculture experiences losses of \$6 billion to \$8 billion annually if county results are weighted by shares in cropland area, but -\$0.7 billion to +\$2 billion if the weights are shares in crop revenue (which gives much more weight to irrigated lands of the West and South). The study shows that agricultural land value is strongly influenced by climate, even after taking into account adaptation. The cross sectional data used in the study reflect agricultural practices that are highly adapted to the local climate, and yet the authors still find large productivity differences related to climate. The evidence indicates that warmer summers have a negative impact on land values, and by implication productivity. This is persuasive empirical evidence that adaptation is unlikely to completely offset the effects of climate change on agriculture.

6.2.2 Sea Level Rise

Based on IPCC (1992a), Wigley and Raper (1992) calculate that as a best guess, realized warming from a 1990 (not preindustrial) base would amount to 2.5°C and sea level rise by 2100 would reach 48 cm, considerably lower than the 66cm predicted by IPCC (1990a).

Both the original and updated IPCC-based estimates refer to the transient, rather than the equilibrium impact of sea level rise. Unlike other damage categories, for sea level the equilibrium effects are far greater and take much longer to occur than the point estimates corresponding to the first year the equilibrium warming is realized. For a discrete warming shock, the sea level continues to rise for up to 500 years (Titus, 1992; Manabe and Stouffer, 1993). A crude way of converting this growing long-term effect into a point estimate is to use a benchmark of 1 metre sea level rise, even though realized increases by 2100 are estimated to be lower.

The costs of sea level rise divide into three types: capital costs of protective constructions, the recurrent annual cost of foregone land services, and the costs associated with increased flood frequencies.

Protection Costs: US EPA estimated that for the United States, a 1 metre rise in sea level by the year 2100 would require \$73 billion to \$111 billion cumulative capital costs to protect developed areas through the building of bulkheads and levees, pumping sand, and raising barrier islands (US EPA, 1989). Assuming that capital costs would be spread over a 100-year period, Cline (1992a) estimated costs in the order of \$1.2 billion for capital construction. Gleick and Maurer (1990) estimate capital construction and maintenance costs for protecting the San Francisco bay from 1 metre rise at \$200 million annually, or a sixth of the US total estimated in Cline (1992a), suggesting the latter may be an underestimate. Fankhauser (1995) estimated

annuitised costs of coastal protection against a 50 cm rise in the order of \$1 billion worldwide, with about half of it occurring in non-OECD countries.

Land Loss: The US EPA (1989) report estimates that under a 1 metre rise scenario unprotected dry land amounting to 6,650 square miles would be lost in the US, and 49% of today's 13,000 square miles of wetlands would be lost (Titus *et al.*, 1992). Titus *et al.* indicate that wetlands preservation programs typically cost up to \$30,000 per acre. Using a more conservative \$10,000 capital cost per acre of wetlands, placing coastal dryland value at \$4,000 per acre, and applying a rental opportunity cost of 10%, Cline (1992a) estimates the annual US losses from a 1 metre rise at \$4.1 billion for wetlands and \$1.7 billion for dryland. Assuming only a 50 cm rise in sea levels, but doubling wetland costs to \$20,000 per acre, at least in developed countries, Fankhauser (1995) obtains a cost estimate of \$45.6 billion annually for foregone land services worldwide, assuming a 33% loss of all remaining wetlands under a 50cm rise. With over 85% of coastal wetland loss occurring in developing countries, low income regions are by far the most heavily affected areas. For the OECD (excluding Canada, Australia and New Zealand) Rijsberman (1991) estimates a loss of coastal wetlands in the order of 48,000 - 64,000 km² for a 1 metre rise, more than 50% of the remaining habitats.

Sea Surges: A 1 metre rise in sea levels could increase the number of people subject to annual flooding by about 20%, according to estimates by IPCC (1994). Particularly at risk would be coastlines along the Indian Ocean, in the South Mediterranean and in Africa, as well as small island states. A number of case studies exist which identify the impact of sea level rise on sea surges in the USA (see Titus, 1987). The annual average damages in Charleston, South Carolina, could double due to an 88 cm sea level rise; the damages of a 100 year storm in Galveston, Texas, could triple (Note that cost-effective protection measures can mitigate this loss). US FEMA-FIA (1991) estimates that the area inundated by a 100-year flood will increase from 19,500 square miles to 23,000 and 27,000 square miles for a 1-foot and 3-foot sea level rise, respectively, by the year 2100. The region most significantly affected would be the Louisiana coast. The expected annual flood damage in the year 2100 increases by 36-58% (\$150 million) for a 1-foot rise and by 102-200% (\$600 million) for a 3-foot rise in sea level. For the European Union, CRU/ERL (1992) calculate that the consideration of periodic flooding would increase the costs of sea level rise by as much as a factor 2.7.

6.2.3 Forests

Global warming is expected to cause a poleward migration of forests, and change in their composition. Sedjo and Solomon (1989) use the Holdridge Life Zone classification system together with GCM projections of changed climate by grid area to calculate that the steady-state effect of 2xCO₂ warming would be to reduce boreal forests by 40% and temperate forests by 1.3% in biomass, but increase tropical forests by 12%. The net change would amount to a decline of 3.7% globally in biomass, and 5.8% in area. Based on these figures, Fankhauser (1995) has estimated annual forestry damages of \$1.8 billion in OECD countries and \$2 billion worldwide, using forest values of 2,000, 400 and 200 \$/km², respectively, for high, middle and low income countries. Because of the positive impact on tropical forests and the use of higher

forest values in developed nations, most forestry damage occurs in OECD countries.

Compared to the equilibrium estimates of Sedjo and Solomon, transient effects over as much as three centuries would be much more severe. Whereas the latitudinal borders of potential location for given species would migrate poleward by 600 to 1,000 km over the next century, the actual migration pace could be as low as 100 km (US EPA, 1989). Dieback along low-latitude boundaries would thus exceed additional growth on the poleward boundaries. Over the next 100 years US forests could lose 23% - 54% of standing biomass in the Great Lakes region and 40% in the West.

On this basis, Cline (1992a) estimates a loss of 40% for US forests. Estimating the value of annual wood extraction at \$10 billion, and allowing for some limitation of losses through reforestation, he estimates net US forest loss from benchmark 2xCO₂ warming at \$3.3 billion annually over the relevant horizon, solely for commercial wood products.

Titus (1992) places US forest damages an order of magnitude higher, at \$44 billion annually (central estimate). He estimates a median percentage biomass loss of 34% in the 30 states he examines. His much higher damage estimates thus stem not from greater biomass loss but from a higher valuation of unit forest area. Using a comprehensive measure that includes recreation and other value, Titus values forested area at \$45 to \$150 per acre per year of forest (above raw land value). The Titus estimates would make US forest loss the largest damage category. At the other extreme, Nordhaus (1991) judges that forest losses would be "small". This range suggests especially large uncertainty for estimates in this category.

6.2.4 Water Supply

Warming is expected to put stress on water supply. A smaller share of precipitation in the form of snow, combined with earlier snow-melt, would mean higher run-off in the winter. Run-off in the spring and summer would correspondingly be reduced. In those areas and/or periods where precipitation declines, the combination of higher evaporation (from warmer temperatures) and lower precipitation would reduce soil moisture and water levels and flows. At the same time, the demand for water would tend to rise with warming, because of increased needs for irrigation and for cooling in electric power production (US EPA, 1989).

The IPCC stresses that river basin run-off is very sensitive to small variations in climatic conditions, because run-off is a residual between precipitation and soil absorption or evaporation; and small changes on any of the underlying variables can cause a much larger proportionate impact on this residual. For the United States, water basin simulation models show that in a warmer, drier climate (+2°C, -10% precipitation), water supply in 18 major water regions covering the bulk of national supply would decline by approximately one-third (calculated from IPCC, 1990b).

For the US, the EPA (1989) predicts that 2xCO₂ warming would reduce annual water deliveries in California's central valley basin by 7% - 16%, even as demand for water rises by about 50%

as early as 2010. For the Sacramento basin, Gleick (1987) estimates that a 4°C increase in temperature would decrease summer run-off by 55% even if there were a 10% rise in precipitation. For the Boston area, Kirshen and Fennessey (1992) apply water balance models to GCM projections for benchmark warming and find that reliable water yields of existing water systems could fall by as much as one-third (GISS, GFDL), but could also rise (UKMO, OSU), because some models predict falling precipitation and others rising. If zero change in precipitation is imposed, the mean model estimate is a decline of 18% in reliable water yield.

Cline (1992a) sets 10% as a central estimate for water supply reduction in the United States from benchmark warming. He estimates national annual withdrawals at 0.4 billion acre-feet, and unit price at \$250 per acre foot. The resulting estimate of annual damage is \$7 billion. Titus (1992) uses a larger volume impact, but lower unit prices to reach a central estimate of \$11.4 billion annual losses. For the European Union CRU/ERL (1992) estimate that the costs of reduced water run-off would amount to ECU 5.8 billion for 1°C warming and 18.8 billion for 4°C.

Fankhauser (1995) uses a somewhat lower percentage volume loss than the US studies, but, at least for OECD countries, a unit price more than twice as high as Cline's. He estimates annual losses at \$34.8 billion for the OECD, and \$46.7 billion worldwide. Again, the high share of OECD damages is due to differences in valuation between regions. In physical units about three quarters of water losses occur in non-OECD countries (see Table 6.5).

In all cases, more efficient water allocation with less low-priced water allocated to agriculture and more to urban use could attenuate losses in water supply, but would aggravate prospective agricultural output losses. Gleick (1992) and Homer-Dixon *et al.* (1993) have emphasized another dimension of water supply effects: the potential for political conflict, such as the dispute over the Jordan river basin that contributed to the 1967 war in the Middle East. From this standpoint associated damages might appropriately include higher defense costs, in terms of economic reckoning, or perhaps more appropriately some unquantified social cost of increased probability of regional wars.

6.2.5 Space Cooling and Heating

Global warming would impose higher air conditioning (space cooling) costs, but reduce heating costs. For space cooling costs in Japan, Nishioka *et al.* (1993) report estimates of a 2% increase in electricity demand per °C warming for temperatures between 24-30°C, and 1% increase for temperatures between 17-24°C. No significant change in demand was found for temperatures above 30°C.

On the basis of detailed energy projections, the US EPA (1989) has estimated that with warming of 3.7°C by 2055, there would be a net increase in US electricity demand by about one-fifth above baseline, requiring additional annual operating costs of \$53 billion and cumulative capital cost increases of \$224 billion. Scaling back these estimates for consistency with present-day economic size and for warming of only 2.5°C, Cline (1992a) estimates annualized damages of \$11.2 billion from higher net electricity requirements under benchmark warming. Arguably, this

estimate is understated, because with global mean warming of 2.5°C, US warming would amount to 3.9°C. Titus (1992) uses the same underlying study to reach a central estimate of \$5.6 billion.

More informally-based estimates of the corresponding savings on space heating are considerably lower, in the range of \$1 billion annually (Nordhaus, 1991; Cline, 1992a). Work by Loveland and Brown (1992) confirms that prospective global warming is likely to increase energy requirements for air conditioning by more than it reduces energy needed for heating. A major reason is that cooling is by electricity, which is much more expensive per BTU than oil or gas (the dominant heating fuels; Titus, 1992). Taking into account anticipated baseline building standards by 2040, Loveland and Brown (1992) estimate that 2xCO₂ warming would raise cooling demands by 35 to 75% for most US areas, and increase peak loads by 6% - 12%. Cline (1993a) applies the Loveland-Brown data to estimate that the weighted average of energy requirements amount to 16 BTU per square foot per degree day for cooling and only 2.6 BTU for heating. As a result, net damages would result from global warming even though in an initial phase warming would actually move average US temperatures closer to 65°F and thus could reduce unweighted degree-days of climatisation. This is not an undisputed result, though. A study by Rosenthal *et al.* (1994), for example, reaches exactly the opposite conclusion, predicting net *benefits* for the US in the order of \$12 billion for 2.5°C warming.

Extrapolating the US EPA (1989) data to other geopolitical regions, Fankhauser (1995) assumed an increase in electricity demand of 3.2% in all regions considered, except for the former Soviet Union, where electricity demand is assumed to decrease by 1%. This results in increased space cooling costs of about \$20 billion in the countries of the OECD and \$23 billion worldwide.

Based on estimated changes in heating and cooling degree days, CRU/ERL (1992) calculated significant benefits from reduced heating expenses in the European Union. Gains in Northern Europe are only partly offset by increased costs in Portugal, Spain and Greece. A 1°C rise in temperature would yield net benefits in the order of ECU 13 billion. For 3°C warming the figure would rise to about ECU 32 billion. These rather optimistic results appear to be mainly due to the dominance of heating over cooling degree days in the baseline case without warming.

6.2.6 Insurance

The insurance industry protects other economic sectors from the financial consequences of unexpected or uncertain events, including weather extremes. As such, it is highly exposed to changes in these extremes and thus to climate change (see section 6.2.14). The basic function of insurance is to transfer financial risk from an individual to a group, i.e. to spread a specific individual loss over everybody potentially affected. The present capacity of natural hazard insurance is about \$100 billion. For comparison, in 1992 hurricane Andrew alone caused an economic damage of \$30 billion, about half of which was insured (Dlugolecki *et al.*, 1994, 1995).

Since 1987, after a relatively quiet period of about 20 years, the insurance industry has been

confronted with a large number of major weather related catastrophes, i.e. events which involved insured losses of over \$1 billion. This increase was caused by a variety of factors, including population growth, increased standards of living, concentration of people and capital in large conurbations, the development of extremely exposed areas, and environmental changes. Although there is no clear connection to the enhanced greenhouse effect, the reaction of the sector is illustrative of what would happen if climate change were to lead to an increase in the number and intensity of extreme weather events (Berz and Conrad, 1993; Dlugolecki *et al.*, 1994, 1995; Leggett, 1993). Initially premiums were increased and cover was restricted. In some areas, such as the Caribbean and the Pacific, insurance and reinsurance supply was temporarily withdrawn after a sequence of hurricanes in the late 1980s and early 1990s. As a further reaction, the insurance sector is currently also considering (Dlugolecki *et al.*, 1994, 1995; Tol *et al.*, 1994):

- (a) alterations in premia determination, incorporating more knowledge on the actual risk (so far, premia have primarily been determined by competition and recent claims);
- (b) changing the product, limiting the insurer's exposure;
- (c) extending the available funds through further pooling and accumulation, in particular in cooperation with governments and banks. This may require alterations of existing fiscal and institutional regulations;
- (d) risk management, i.e. getting involved in restricting the damage caused by weather events;
- (e) lobbying for, and investing in environmentally sound policies and projects.

While a number of these points help in reducing the overall exposure to weather hazards, many merely affect the exposure of the insurance sector itself. Only limiting the insurers' exposure obviously leads to an expansion of the exposure to others. Little research has been done to assess the consequences of such a policy on households, industry and government.

6.2.7 Other Market Sectors

Construction: Nordhaus (1991) suggests that the construction sector in temperate climates would be favourably affected by global warming because of a longer period of warm weather. However, although construction is adversely affected by frost, it is also inhibited by rainfall, and GCMs typically predict an increase in global mean precipitation by about 8% as the consequence of benchmark 2xCO₂ warming (IPCC, 1990a). The IPCC notes adverse effect of rainfall on economic activity more generally, and cites Parry and Read to the effect that "rainfall is responsible for more delays than any other climatic variable" for UK industry (IPCC, 1990b, p. 5-23). However, estimates are not available on the net effects of warming and increased precipitation on construction or industry more generally.

Tourism and Leisure Activities: Studies by the Canadian Climate Program Board suggest that as a consequence of a shortened period of snow cover Quebec could lose 40 to 70% of skiable

days. In Ontario, the shorter skiing season may cause a loss of up to \$50 million in revenue (Canadian Climate Program Board, 1988a, b). Losses would presumably be larger in relative terms in US ski areas, where the temperature base is already higher. Annual US ski activity amounts to an estimated \$5.6 billion and 53 million skier visits (Waters, 1990). Assuming a 60% reduction from benchmark warming, and allowing for released productive labour and capital, Cline (1992a) estimates ski industry losses at \$1.7 billion annually.

The tourist industry will also be affected by beach washing and the inundation of beaches (Baan *et al.* 1993), as well as likely coral reef death and other ecosystems loss (US EPA, 1989)³. These impacts could be particularly significant for small island states, where tourism frequently accounts for over a third of GDP (see Turner *et al.*, 1994). On the other hand, there could be gains from global warming in other leisure sectors such as camping, boating and sunbathing. The Ontario case study, for example, predicts an increase in the camping season of up to 40 days in some areas (Canadian Climate Program Board, 1988b). In many regions, however, an increase in summer activities could be hampered by increased rainfall. CRU/ERL (1992) have developed a "comfort index", using temperature, sunshine and rainfall as indicators of the suitability of climates for leisure activities. Using this index and figures on current European tourist revenues they estimate that 1°C warming could benefit tourism in the EU by about ECU 4.7 billion. As temperature rises, the impact value at least in Southern Europe soon becomes negative, though.

Urban Infrastructure: The US EPA (1989) has examined the impact of global warming on urban infrastructure costs. For coastal cities, sea level rise or more frequent droughts would increase the salinity of coastal aquifers and tidal surface waters, requiring a response where these are the sources of metropolitan water supply. In addition, more frequent and intense storms would likely overload existing storm sewer systems. Using US EPA studies for New Orleans, New York, Philadelphia, and Miami, Cline (1992a) suggests that annualized damages of benchmark warming for US urban infrastructure could amount to \$100 million yearly.

6.2.8 Health

There is a U-shaped relationship between mortality and outdoor air temperature. Death rates increase as a consequence of both heat waves and very cold weather. The lowest mortality rates are found at temperature levels of about 16-25°C (Kunst *et al.*, 1993; Haines and Parry, 1993). Global warming could lead to an increase of heat related deaths from coronary disease and stroke which is likely to more than offset the reduction in winter mortality. Air pollution increases the occurrence of respiratory diseases (emphysema and asthma), and longer, warmer summers are expected to increase the severity of air pollution.

In addition to directly heat related health effects, there could be indirect losses from increased

vector-borne diseases (e.g. carried by ticks and mosquitoes). The risk areas of diseases like malaria or yellow fever may shift as their vectors adjust to new climate conditions (Haines and Parry, 1993). WHO (1990), for example, suggests that the so far disease-free highlands of Ethiopia, Indonesia and Kenya might be invaded by vectors. A study for Indonesia predicts a fourfold increase the incidence of dengue fever and a 20% increase in malaria cases (Asian Development Bank, 1994). Vector-borne diseases may also spread into developed countries. Hohmeyer and Gärtner (1992) estimate that under 2xCO₂ an extra 200 million people could be exposed to malaria worldwide. Simulations for the United States on a possible increase of malaria are however inconclusive (US EPA, 1989).

The increased occurrence of flooding could lead to a higher incidence of diseases associated with poor sanitation standards, particularly in developing countries. For Indonesia it has been estimated that by the year 2070 cases of diarrhoea could raise to over 900 per 10,000 inhabitants, compared to 300 cases/10,000 people in 1989 (Asian Development Bank, 1994).

Kunst *et al.* (1993) have analysed the statistical relationship between mortality and air temperature in the Netherlands. They found that a 30 days increase in air temperature of 1°C above its ideal level would lead to a rise in mortality of 1.1 - 1.9%. A 1°C drop from the optimum would cause a slightly lower rise of about 0.8 - 1.3%. For the UK Langford and Bentham (1993) estimate that the higher temperatures predicted for 2050 (about 2.5°C) could result in some 9000 fewer winter deaths per year. See Chapter B4 of IPCC Working Group 2, Second Assessment Report, for a comprehensive overview. Most economic studies use Kalkstein (1989) as a basis. Kalkstein has used statistical methods to analyse the mortality impact of changed weather conditions under 2xCO₂ for 15 major US cities (US EPA, 1989; Kalkstein, 1989). Even after accounting for induced acclimatization (based on mortality statistics for control cities with comparable present climate conditions), he finds that increased summer deaths substantially exceed decreased winter deaths. Cline (1992a) and Fankhauser (1995) weight these results by population and extrapolate that benchmark warming would increase mortality by about 27-40 persons per million population, depending on the warming scenario. Without acclimatization this figure would be about six times higher. For the United States the more conservative figure including acclimatization translates into 6,600 to 9,800 additional deaths annually at present US population scale.

Mortality effects could be particularly damaging in the more vulnerable countries of the developing world. In Shanghai, for example, death rates from heat stress are currently over twice those in New York City (Haines and Parry, 1993). Health problems associated with hot spells are also significant in Bangladesh (Asaduzzaman, personal communication, 1994) and Pakistan (Asian Development Bank, 1994). Using uniform mortality rates, Fankhauser estimates that about 115,000 casualties will occur in non-OECD countries, compared to some 23,000 in the OECD (for 2.5°C warming, see Table 6.5). Tol (1994b), using the same estimates but without scaling to 2.5°C warming, arrives at a figure of 215,000 casualties worldwide.

Expressing the value of this loss in monetary terms is controversial (see Box 6.1). Cline (1992a) uses lifetime earnings to place statistical life valuation at a conservative \$595,000 and reaches

³ Some of these impacts may, as forgone use value, be included in estimates for ecosystems loss (see Section 6.2.13).

a corresponding estimate of \$5.8 billion in annual US losses from benchmark warming. Using higher values Titus (1992) obtains annual damages of \$9.4 billion for the US. Fankhauser use value-of-statistical-life estimates of \$0.1 to 1.5 million, depending on regional income levels, and obtains mortality damages of \$10 billion in the US, \$34 billion for the OECD and \$49 billion worldwide. If an identical value of \$1 million for all lives were used worldwide this latter figure would rise to almost \$140 billion. Tol (1994b) assesses a statistical life at \$250,000 + 175*(income per capita). With worldwide mortality costs of \$188 billion health damages account for more than half of his aggregate estimate of warming damages.

[Box 6.1]

6.2.9 Air Pollution

A warmer climate could aggravate some urban pollution problems. In the United States, tropospheric ozone is the most severe problem in terms of the number of persons living in areas with air quality indexes that violate national standards (75 million persons in 1986). Total suspended particulates (TSP) and carbon monoxide are also important (41 million each). TSP is also implicated in widespread health damage in the developing world and the economies in transition.

Numerous studies confirm that ozone concentrations rise with temperature (see e.g. IPCC, 1990b). The US EPA has summarized various US estimates with the conclusion that a 4°C rise in temperature (about what could be expected for the United States under 2.5°C global mean warming) could cause an increase in peak ozone concentrations by 10%. The result would be to double the number of cities in violation of the air quality standards from 68 to 136, causing most midsize and some small cities in the Midwest, South, and East to be added to the list of those presently in violation.

The US EPA has applied its past models relating ozone concentrations to emissions of volatile organic compounds (VOC) to estimate that, to offset benchmark 2xCO₂ warming, it would be necessary to reduce VOC in the United States by 700,000 tons from a year-2000 expected base of 6 million tons. At an estimated cost of \$5,000 per ton, the agency calculates that the resulting costs would amount to \$3.5 billion annually (US EPA, 1989). Cline (1992a) uses this figure as an estimate of US air pollution damage to be expected from benchmark warming. As an indicator air pollution control expenditure in 1987 was \$27 billion (US EPA, 1990b).

Titus (1992) estimates US tropospheric ozone damage from benchmark warming at \$27.2 billion annually. This is almost an order of magnitude higher than Cline, although both figures are based on the US EPA (1989) estimate. The difference appears to be that Titus projects a high baseline of VOC (volatile organic compound) emissions, at 3% growth and reaching an implied 70 million tons by 2060, whereas the US EPA estimate is based on the present scale of emissions. Although some allowance for growth in the base is appropriate, it seems unlikely that the pollution baseline would grow faster than GDP and energy output.

Instead of calculating the additional expenditures needed to maintain present air quality standards, Fankhauser (1995) estimates the extra damage occurring if air quality standards were allowed to deteriorate. Assuming increases in NO_x and SO₂ emissions of 5.5% and 2%, respectively, he estimates additional air pollution damages of \$12 billion in the OECD, and \$15 billion worldwide (see also the cost of air pollution estimates provided in Table 6.13).

6.2.10 Water Pollution

Titus (1992) and Nishioka *et al.* (1993) have identified water pollution as a category with potentially large damages from global warming. They predict a likely decline in river flow under global warming because of lesser water run-off. Because rivers serve to carry away waste, lesser river flow leaves more waste to be removed by emissions controls. Nishioka *et al.* also discuss a possible decrease in the water quality of lakes through increased algae growth.

In assessing the impact of water pollution on the US Titus assumes that the discharge of pollutants would change by the same proportion as river flow. He cites US EPA estimates to establish a base of \$64 billion for US water pollution control costs in the year 2000 (at constant 1990 prices). Based on estimates by Waggoner and Revelle, he calculates that run-off declines by 2% - 4% if either precipitation decreases 1% or temperature increases by 0.4°C. Setting the elasticity of control costs (percent change for a one percent change in river flow) at 1 to 1.7, Titus calculates that water pollution control costs imposed on the United States by benchmark global warming would be in a range of \$15 billion to \$67 billion annually, with a central estimate of \$34 billion. Like Titus' estimate for forest damage, this estimate dwarfs typical damage calculations for most other individual categories. Yet water pollution is one of the most under-researched aspects of economic damage.

6.2.11 Migration

Global warming could increase the displacement of people because of coastal inundation from sea level rise, increased droughts (e.g. from Mexico to the United States), and possibly increased tropical cyclones (e.g. from the Caribbean to the United States). Schelling (1983) views migration as an efficient adaptive response to global warming. However, presumably a cost should be imputed to the utility loss by families compelled to migrate (Jansen, 1993). Indeed, historically peoples have often fought wars to avoid being forced to leave their homelands. Tol (1994b) arbitrarily puts this loss at three times the average income per capita in the region of departure. This is reflected in Table 6.6. There is also a cost to the recipient host country. In many countries, e.g. in Europe and the United States, the costs of incorporating immigrants into the social welfare infrastructure are already a politically sensitive source of social and budgetary pressure.

Cline (1992a) reports estimates of 640,000 legal immigrants into the United States annually in recent years, in addition to perhaps 130,000 illegal immigrants (Goering, 1990). He hypothesizes an increase of 25% in illegal immigration and 10% in legal immigration as a consequence of benchmark warming. Based on total per capita spending by state and local governments, and

assuming 18 months before an immigrant's tax payments cover the family's social infrastructure costs, Cline estimates costs at \$4,500 per immigrant; Ayres and Walter (1991) similarly cite a figure of \$4,000 per refugee accepted by the United States. Cline (1992a) estimates annual immigration costs to the United States from 2xCO₂ warming at \$450 million. The hardship and stress suffered by refugees remains uncounted, though. Fankhauser (1995) has extended the Cline estimates to the world as a whole, assuming that current migration patterns will hold (see Table 6.5).

6.2.12 Human Amenity

Mearns *et al.* (1984) use statistical distributions of current temperatures to explore the impact of global warming on extreme temperature events for the United States. In their base case, they increase mean temperature by 3°F (1.7°C) and hold the variance and autocorrelation of daily temperatures constant. Under these assumptions, they calculate that the frequency of heat waves (defined as 5 consecutive days with a maximum temperature of at least 35°C) would multiply three-fold (estimated for Des Moines, Iowa). There is reason to believe that people would be willing to pay something to avoid a threefold increase in the incidence of heat waves. At the same time, global warming would reduce disamenity of severe winters in colder areas. The net balance under benchmark warming is unclear. As suggested below, however, for much higher warming over the very-long term, the amenity damages would be more likely to dominate.

Cline (1992a) provides an order of magnitude estimate of the value of the disamenity caused by a sharp increase in the number of hot spells in the USA; assuming that people are willing to pay 0.25% of their income to avoid this and other disamenities, a \$10 billion loss per year results⁴.

Leary (1994) has surveyed the available empirical evidence on the implicit valuation of amenity due to local climatic variation in the USA. The results of this study are:

- (a) that individuals value changes in climate and are willing to accept lower wages, or pay more for property, in return for an improved local climate. Some migratory patterns are explained by climate differences.
- (b) in the USA these values appear to be substantial, ranging from hundreds to thousands of US dollars.
- (c) households prefer sunny, mild climates. Increases in winter temperature and the number of sunny days are favoured, while higher summer temperatures deter migrants, so that hot summers appear to be a disamenity.

While these findings are intuitively appealing, characterisation of "climate preferences" is not,

⁴ As the estimate is purely speculative, it is excluded in the central estimates of that study, and from Table 6.4 below.

however, robust across the studies evaluated and it is not possible therefore to say whether climate change will, on balance, increase or decrease climate amenity. As with other aspects of the economics of climate change, these results are relevant only to the USA and, perhaps, other industrialised temperate zones where housing and labour markets respond to differentials in housing and work characteristics.

Amenity effects would vary by region, tending toward damages in presently warm areas and gains in presently cold areas. Potentially amenity valuations could be large in absolute terms, because they apply to the entire income base of the population. However, the tendency toward neutralization by the differential effects among geographic regions and between seasons would tend to reduce the overall magnitude of amenity effects.

6.2.13 Ecosystems and Biodiversity Loss

Perhaps the category in which losses from global warming could be among the largest, yet where past research has been the most limited, is that of species loss. Existing figures are all rather speculative. There is a serious need for conceptual and quantitative work in this area.

The US EPA (1989) has noted in general terms the risk of increased species extinction from global warming, because of changes in habitat, predator/prey relationships, and physiological changes. It cites the poleward migration of forests as a major reason to expect stress on species, especially in view of natural and manmade barriers to animal migration. Another category of likely species loss is that of coral reefs, as suggested by recent instances of coral death from El Niño warming (Glynn and de Weerd, 1991).

Economists identify three types of species value: direct and indirect use value (e.g. plant inputs into medicine and the role of forests in protecting watersheds, respectively); option value (preserving a species to retain the possibility that it may be of economic use in the future); and existence value (like the value society places on a rare work of art). Table 6.2 (based on Pearce, 1993) summarises the results of "contingent valuation" sample survey estimates of what the public would be willing to pay to preserve an endangered *animal species*. Average values range from \$1 - \$18 per person per year for preservation of an individual species, with a maximum of \$40 to \$64 obtained for humpback whales. The willingness to pay figure for the preservation of entire *habitats* is somewhat higher, with a range of \$9 - \$107 per person and year.

[Table 6.2]

The economic value of *plants* is dominated by their potential significance for medicinal purposes. Pearce (1993) notes that in the United States about 40 plant species accounted for plant-based prescription sales of some \$15 - 20 billion/year during the 1980s (at 1990 prices). This would imply an economic value of at least \$300 million per successful species and year. The figure could rise up to several billion dollars if values were calculated on the basis of deaths avoided using statistical life valuation. These are averages and some species are clearly more valuable than others. Nevertheless, the figures can provide some indication of the lost pharmaceutical

value from disappearing species. Some 60,000 plant species are expected to become extinct over the next 50 years. Given that the probability of a plant species yielding a successful drug is between 1:10,000 and 1:1,000, between 6 and 60 plant species with potential drug value could thereby be lost. With a mean loss of 30 such species, and applying the price range just noted, Pearce (1993) calculates that the annual losses for the United States could amount to between \$8.8 billion and \$180 billion (assuming there are no synthetic substitutes). By implication, if global warming were to increase these expected losses by just 10%, loss of plant species alone could cause annual US losses from global warming on the order of \$1 billion to \$18 billion in gross value terms (less, once costs are allowed for).

Monetary estimates of ecosystem damages through climate change are invariably *ad hoc*. Fankhauser (1995) cites the Pearce (1993) survey (see Table 6.2) to arrive at a willingness to pay estimate of \$30 per person per year to avoid species and habitat loss from global warming. Total costs amount to about \$40 billion annually for the world as a whole, with about one third occurring in developing countries. Cline (1992a) arrives at an estimate of about \$4 billion annually as a notional value of species loss from benchmark global warming for the US, but suggests that the figure could as easily be an order of magnitude higher (\$40 billion). The estimate is based on an extrapolation of observed US public expenditures for the preservation of one particular species (the spotted owl).

6.2.14 Extreme Weather Events

Along with changes in the mean climate, changes in the extremes can be expected. Changes in the extreme values of meteorological variables are not necessarily proportional to changes in the mean. If, for instance, mean precipitation shifts upwards while at the same time the variability increases, the number of droughts might remain roughly the same whereas the number of floods rises drastically (Graßl *et al.*, 1995). Also, extremes are of more importance in studying the socio-economic impacts of climate change. Most societies, in accommodating to the environment they live in, have developed strategies to cope with only a limited range of climatic events. Within this range, the 'normal' variability is regarded as a resource while the extremes constitute hazards (Heathcote, 1985). All kinds of adaptation mechanisms, such as insurance, exist to deal with these extremes. However, adaptation is costly, and therefore limited. Prevention is only to a certain extent better than cure.

Measures to adapt to natural hazards comprise a mix of physical, economic and societal features. At the physical level, there is the design of buildings and protection constructs, such as dikes. At the economic level, there are personal savings and insurance to cover the damage. At the societal level, there are social safety nets, charity, and the government. Different adaptation mechanisms exhibit different degrees of flexibility; an insurance policy is valid for one year, an average Dutch dike has a lifetime of about two centuries. Flexibility is enhanced as adaptation measures are under constant pressure of changes in population and industrialisation, and their densities, and the legal, economic, financial and social systems (Berz and Conrad, 1993). Additionally, climate constantly changes.

It is clear from the above that the qualification 'extreme event' or 'disaster' is a social construct, which is hard to measure. The continuously changing mechanisms to cope with natural disasters complicate this matter further. Also, while the direct impacts of natural disasters may be harmful, indirect impacts are hardly measurable on a macro-scale (Albala-Bertrand, 1993), and the event might set in motion a chain of beneficial changes, compensating for the initial losses. Finally, a disaster is not only local in a social and temporal sense but also in a spatial sense. The current generation of GCMs is not capable of reproducing present extremes very well, certainly not without spatial filtering, let alone capable of deriving changes in extremes due to the enhanced greenhouse effect (Graßl *et al.*, 1995).

Little systematic research into the impact of changes in extreme weather events has been carried out. The natural disaster impact community, structured by the United Nations' International Decade for Natural Disaster Reduction, although aware of the enhanced greenhouse effect, mainly studies present risks (Olsthoorn *et al.*, 1994). The climatic change impact community focuses on changes in the mean, although attention is increasingly paid to extremes. So far, most attention has been paid to tropical cyclones, changes in which appear to be one of the most controversial questions of climate change research.

Tropical Cyclones: On the basis of $2\times\text{CO}_2$ simulations with the GISS GCM, Hansen *et al.* (1989) conclude that global warming would bring "increased intensity" of "both ordinary thunderstorms and mesoscale tropical storms". Wendland (1977) has provided empirical support for the relationship of hurricanes to ocean surface temperatures. From monthly data for 1971-81, the frequency of hurricanes is closely related to the size of ocean area with temperature over 26.8°C , and the relationship is exponential. Similarly, Emanuel (1987) argues that tropical cyclones are "particularly sensitive to sea surface temperature".

Higher sea surface temperature causes a larger drop in barometric pressure. Applying a 2.3°C to 4.8°C range of GCM estimates for increased August temperatures in the tropics under $2\times\text{CO}_2$, Emanuel estimates that the destructive potential of hurricanes could rise by 40% - 50%. Houghton (1994) expects an increase in both the frequency and severity of tropical and other storms. Haarsma *et al.* (1993) report a 50% increase in the number of tropical disturbances under $2\times\text{CO}_2$. The maximum windspeed would increase by 20%. The Australian CSIRO 9 GCM also points at an increased cyclone activity, and shows that a threefold increase is not impossible (Ryan *et al.*, 1992). Other results, on the other hand, give a less clear cut picture (see e.g. Broccoli and Manabe, 1990; Maunder, 1994; Raper, 1993). Idso *et al.* (1990), for example, argue that tropical sea surface temperatures would increase very little with global warming while the tropical tropopause could become more stable, leading to less intense cyclones. IPCC (1990a) judges that the impact of global warming on storm intensity is "ambiguous".

The existing economic estimates tend to include increased hurricane damage as part of the damage to be expected from global warming (see Tables 6.4 to 6.6). Thus, Cline (1992a) reviews past hurricane damage for the United States, and applies the 50% increase implied by Emanuel to estimate that benchmark warming would impose average annual damages of \$750 million. Considering that the IPCC did not indicate any likelihood that tropical cyclones might

decrease, the expected direction is an increase. Because the most recent hurricanes have imposed even larger damages than most of those surveyed below, a lower implicit probability to account for uncertainty, applied to a higher damage base, could still yield central damage estimates comparable to those reported here.

In an average year about 70 to 80 tropical cyclones are recorded worldwide, causing damages of about \$ 1.5 billion, with a death toll of 15,000 to 23,000 lives (Smith, 1992; Bryant, 1991). The occurrence of cyclones is distributed unevenly over the globe. Northern regions like the former Soviet Union and Europe, for example, are only marginally affected. Based on the natural hazard map of Berz (1990), Fankhauser (1995) has estimated that the United States is affected by 7% of all cyclones, while another 7% occur in China and 29% in OECD nations (Australia, Japan, New Zealand and the US). Combining this distributional pattern with the Smith/Bryant figures and the Emanuel estimate, Fankhauser (1995) arrives at an additional 8,000 cyclone casualties, practically all in developing countries. Using the same value-of-life estimates as for health damages and adding in \$630 million additional property damages total worldwide hurricane damage amounts to about \$2.7 billion.

These average figures are overshadowed, however, by the disastrous consequences of individual events, with poorer countries, especially small islands, being particularly vulnerable (see Box 6.3). In 1970 a cyclone caused more than 500,000 deaths in what is now Bangladesh. In 1985 a similar disaster in the same region killed another 100,000 people (Bryant, 1991). The \$2.7 billion figure may therefore underestimate the true costs.

Extra-Tropical Storms: Dlugolecki *et al.* (1994, see also Munich Re, 1993) report worldwide losses due to major windstorm events to have averaged \$2.0, \$2.9, and \$3.4 billion (1990 prices) for the decades of the 1960s, 1970s, and 1980s, respectively. For 1990-1992 this figure has risen to \$20.2 billion. The larger part of these damages is due to tropical cyclones, however. The 1990 storms in Europe (Daria, Herta, Vivian and Wiebke) resulted in a total loss of DM 25.3 billion (Munich Re, 1993). However, while storm damages have clearly increased over the last decades, it is not clear how much of this rise is attributable to global warming. The results of Changnon and Changnon (1992) and CATMAP (Clark, 1988; 1991) indicate that most of it is probably due to socio-economic developments.

River Floods: Little information is currently available regarding the socio-economic impact of changes in the frequency and intensity of river floods (see Arnell and Dubourg, 1994).

Droughts: The impact of drought on agriculture has already been treated in Section 6.2.1. As an alternative way to estimate agricultural damage, Cline (1992a) reports an annual loss imposed on US agriculture by increased drought of \$18 billion/year. Water supply in general is dealt with in Section 6.2.4. The effect of decreased water run-off is partly dealt with in the section on water pollution (6.2.10). A further impact of drought is land subsidence. The 1975-1976 drought in England and Wales, for example, led to a cost of £100 million to the insurance industry (Doornkamp, 1993). By 1979 the costs had amounted to £220 million.

Hot and cold spells: The impacts of hot and cold weather spells on human amenity and health were treated in the respective sections above.

Total Losses: Table 6.3 (after Limbert, 1993) provides total fatalities attributed to weather events between 1989-1992 as reported for the six WMO regions. The average number of lives lost to natural hazards is more than 4,000 per year, with the highest proportion occurring in Asia. This is likely to be an underestimate, because some major events are not included. As already mentioned in 6.2.6, the losses due to natural hazards have increased dramatically over the last decade. It is unclear which fraction of casualties can be attributed to global warming, however. The strong trends in losses allow us to display only short term averages.

[Table 6.3]

6.2.15 Damage Estimates: Summary

Tables 6.4 to 6.6 summarize the principal existing estimates of global warming damage for major regions of the world. In the United States, losses from benchmark $2\times\text{CO}_2$ equivalent warming reach over 1% of GDP in the Cline, Fankhauser and Tol compilations, and some 2.5% of GDP in the central Titus estimates. Titus specifies a lower and upper end of his range of estimates, at 0.8% and 5.4% of GDP, respectively. It should also be noted that the Titus estimates are based on GCMs with average warming parameters of about 4°C , higher than the IPCC's best guess of 2.5°C . Estimates for other OECD countries are mostly within the same order of magnitude of 1-2% of GDP (see Table 6.6).

Less comprehensive estimates by Nordhaus (1991), again for the US, arrive at a direct calculation of only 0.26% of GDP, primarily from sea level rise; but Nordhaus also sets 1% of GDP as a reasonable central estimate. The CRU/ERL (1992) estimates for the European Union, on the other hand, are significantly higher, with costs in the order of 1.6% of national income *per degree of warming*. The principal reason for this is a very high assessment of sea level rise damages. By augmenting sea level rise costs by a factor 2.7 to account for storm surges, the study may overestimate damages. On the other hand, their assessment of non-sea level rise impacts appears to understate true damages, with an overall beneficial outcome in these categories.

[Table 6.4]

[Table 6.5]

With the possible exception of the Titus calculations and, for some categories, the CRU/ERL estimate, these damage figures seem likely to understate the true impacts, for two reasons. First, several effects are not (fully) quantified (e.g. non-tropical storms, droughts, morbidity, transport). These are probably predominantly harmful, with the possible exception of climate amenity values and tourism for some regions. Second, adaptation is not fully taken into account. Third, the figures are far from exact and one should allow for a considerable range of error. Many are deliberately kept conservative. Species loss valuation in particular could be far higher.

It should also be emphasized that the estimates in Tables 6.4 to 6.6 refer to central warming expectations. The corresponding damages for upper-bound warming would be higher, and more than linearly so. Finally, when moving from the question of damage estimation to that of abatement benefits, a number of non-climate change related benefits need to be taken into account (see Section 6.7).

Regional differences can be substantial, as is exemplified by the estimates for developing regions and the former USSR (see also Section 6.5). For the former Soviet Union damage could be as low as 0.7% of GNP or even negative (ie climate change is beneficial). The negative figure by Tol (1994b) mainly stems from large beneficial impacts in the agricultural sector. In the Fankhauser study, on the other hand, possible beneficial yield impacts are more than offset by the adverse impact of increased world prices on food imports. The region will also suffer from particularly high health and air pollution costs. The extremely high estimate for the Asian regions and Africa, on the other hand, are predominantly due to the severe life/morbidity impacts. As explained above, both the quantitative assessment and the underlying value-of-life estimates are very volatile, and the probability range of total damage is particularly wide for these regions.

Damage is likely to be more severe in developing countries, compared to developed countries as is shown in Table 6.6, and discussed in Box 6.3. Table 6.6 reports damages in non-OECD countries of about 1.6-2.7% of GDP, some 50% higher than the OECD average. The main causes for this high estimate are health impacts and the high portion of natural habitats and wetlands found in developing countries. Although the data for the non-OECD estimates are significantly weaker, they provide a clear indication that global warming will have its worst impacts in the developing world, with a damage of probably at least 2% of GNP for $2\times\text{CO}_2$.

[Table 6.6]

In general, the estimates in Tables 6.4 to 6.6 show a relatively narrow band for central damage calculations for the United States, and for developed countries in general. It is important to recognize, however, that this field of estimates is probably biased toward convergence. The reason is that, with the exception of CRU/ERL (1992), the underlying sources of many of the estimates are the same, particularly US EPA (1989). The convergence tends to become extrapolated to other regions, too, considering that several of the international estimates in Fankhauser (1995) and Tol (1994b) are obtained by extrapolation of the US estimates. The similarity of the estimates should therefore not necessarily be interpreted as evidence of their robustness. There remains a substantial degree of uncertainty in the estimates. Nevertheless the relative ranking of regions appears to be reasonably robust, with the most severe impacts to be expected in Asia and Africa, and northern and developed regions suffering less.

The worldwide estimates of Table 6.6 are expressed as the total sum of regional damages relative to the global sum of GDP. As discussed in Box 6.2, it can be argued on equity grounds that there should be greater weights placed on impacts for low-income countries than would result from simply applying their shares in the global income base. As shown in the box, under

one commonly used utility function (logarithmic), equity weighting would tend to raise the global aggregate damage measure. This would especially be the case for the Tol estimates, where damages are particularly high in developing countries.

[Box 6.2]

[Box 6.3]

It is useful to consider the results of an opinion survey of 19 global warming experts from both physical sciences and economics (Nordhaus, 1994a, see Table 6.7). For a 3°C actual warming by 2090, estimated global damages ranged from zero to 21% of gross world product, with a mean value of 3.6%. For a more rapid and severe warming (scenario B) the mean increases to 10.4% of GDP. Diverging from the estimates of Table 6.4, virtually all of the respondents judged that more than half of the damages would occur in the market sectors (such as agriculture), rather than in sectors outside the standard system of national accounts (biodiversity, amenity)⁵. The three natural scientists included in the survey gave the highest damage estimates, whereas the lowest estimates were from eight economists who had not done research on global warming. The reason for this discrepancy is unclear. One implication of the survey seems to be that the perceived scope of global warming damage is higher among natural scientists than among most economists. Natural scientists also attach a higher probability to the possibility of a calamitous outcome. This pattern suggests another reason why the estimates reported above may be under- rather than over-statements.

[Table 6.7]

6.3 Damage Estimates for Longer Term Warming

Most analyses of global warming focus on the doubling of atmospheric concentrations of carbon equivalent of all greenhouse gases above preindustrial levels. IPCC (1990a) indicates that concentrations could reach this benchmark as early as 2025 under business as usual policies. Yet there is no reason to believe that greenhouse gas emissions and atmospheric build up would stop at that point. A long term view on climate change impacts is therefore important, even though the need for socio-economic forecasts over more than a century makes this task extremely problematic (see also Section 6.2).

Sundquist (1990) has estimated that there are sufficient fossil fuel reserves to permit emissions of carbon dioxide to rise such that its atmospheric concentration might reach 1600 ppm by the year 2200, before the exhaustion of reserves would reduce emissions and allow concentrations to plateau through 2300 and then moderate back to about 1200 ppm over a 400 year period as the consequence of deep-ocean mixing. With pre-industrial concentrations of 280 ppm, this scenario amounts to a potential rise of nearly six-fold in carbon concentrations alone. Cline

⁵ Nordhaus (1994a) includes human health in the non-market sectors.

(1992a) uses a 300 years time horizon to investigate the very-long-term impacts of global warming. On the basis of fossil fuel (primarily coal) reserves estimated by Edmonds and Reilly (1985), he concludes that as much as 14,000 GtC in carbon could be available for use at reasonable economic cost. He applies three leading energy-carbon models (Reilly *et al.*, 1987; Nordhaus and Yohe, 1983; Manne and Richels, 1992) to project carbon emissions through the year 2100, and extrapolates their rates late in the 21st century through 2275. Average emissions rise from 7 GtC today to 20 GtC by 2100 and 56 GtC by 2275.

Under the assumption that atmospheric retention remains at its recent 50% level, Cline estimates carbon concentrations on the order of 2,200 ppm by 2275, or about eight times pre-industrial levels. The corresponding increase in radiative forcing would reach about 13 Wm^{-2} , from carbon alone, or some 19 Wm^{-2} from all greenhouse gases. With the central IPCC climate sensitivity parameter (Λ) of 2.5°C for 4 Wm^{-2} , the resulting mean warming would be almost 12°C . On this basis, Cline (1992a) sets 10°C (the lowest range from the three emissions models) as a tentative benchmark for ultimate warming over a 300 year period.

This would take the earth back to the climate of the mid-Cretaceous period 100 million years ago, when mean temperatures were an estimated 6°C to 12°C higher than today (Hoffert and Covey, 1992). If instead the upper-bound climate sensitivity parameter is applied ($\Lambda = 4.5^\circ\text{C}$), very-long-term warming could reach approximately 18°C .

Recent simulations of the GFDL (Geophysical Fluid Dynamics Laboratory) general circulation model at Princeton University tend to confirm this range of 10 - 18°C for baseline warming. Manabe and Stouffer (1993) examine the effects of a quadrupling of pre-industrial carbon dioxide equivalent by 140 years from now. They note that this level amounts to a 1% annual increase in CO_2 -equivalent concentration, consistent with the IPCC "business-as-usual" scenario. The equilibrium mean surface air temperature increase reaches 7°C , while the actual transient warming is 5°C . Manabe and Stouffer do not argue that atmospheric concentrations will in fact stop rising after 140 years. Instead, their interest is in examining the consequences of this specified century-scale scenario. They find that sea-level rise from thermal expansion alone reaches 1.8 meters by the 500th year, and would presumably be much greater if the effect of melting of ice-sheets were taken into account.

After first conducting an economic analysis of global warming using comparative static techniques with carbon doubling as the benchmark (Nordhaus, 1991), Nordhaus (1994b, 1993a, b) has also adopted a centuries-scale horizon for his dynamic model DICE. However, Nordhaus' baseline involves warming of only 5.5°C by 2275, because of lower emissions (31 GtC by 2275) and lower atmospheric retention. Lower emissions stem from lower growth expectations, as Nordhaus' model assumes progressive slow-down in technological change that has the effect of limiting growth. Global product by the year 2275 is a multiple of only 7 times today's output in the DICE baseline, but 26 times in Cline (1992b), suggesting that diverging economic assumptions may be even more important than different assumptions about the scientific parameters for such long-term analysis.

If 10°C is used as a guideline to potential warming over a 300 year horizon (or much sooner if the upper end of the climate sensitivity parameter range proves valid), the corresponding economic damages could be very large. The central reason is that in many categories, damage is likely to rise non-linearly with warming. As one example, water run-off is a residual between precipitation, which rises linearly with global warming (and primarily in the higher latitudes), and evapotranspiration, which rises non-linearly (see e.g. Rind *et al.*, 1990). Similarly, Yohe (1993) finds that at intermediate sea level rise, a doubling of the rise causes damages to rise about 2-1/2 fold; and above 60 cm, a doubling of the rise causes a tripling of damage.

It seems likely that the damages of high, very-long-term warming would be especially pronounced in the non-market sectors. Human amenity could face major losses, even after accounting for adaptation. For example, Cline (1992a) estimates that with 10°C global mean warming, among 66 major US cities the number with average daily temperatures in July exceeding 90°F would rise from 18 presently to 62.

Attempts to quantify long-term damage are rare and highly speculative in nature. Most often, long term damage estimates are simple extrapolations of the $2\times\text{CO}_2$ equilibrium case, using different assumptions about the degree of non-linearity in the damage-temperature relationship. Cline (1992a) uses a relatively modest degree of non-linearity for most effects, with an overall damage function exponent of 1.3. Nordhaus (1993a, b) applies a quadratic damage function in his main scenario, while Peck and Teisberg (1992) consider several specifications, including quadratic and cubic functions. Table 6.8 reports the central estimates in Cline (1992a) for US damage from 10°C warming. Against present economic scale, they amount to \$335 billion annually, or 6% of GDP. However, the figure is only illustrative.

Assuming a quadratic temperature-damage relationship, US damage from 10°C warming would amount to over 17% of GDP. If more allowance is made for such categories as species loss the central range could rise to 2% of GDP for $2\times\text{CO}_2$ at 2.5°C and 12% of GDP at 10°C . With upper-bound warming, the very-long-term damage reaches 20% of GDP. In the long term scenario in the Nordhaus (1994a) poll of experts, respondents predicted a mean damage of 6.7% of GDP for 6°C warming by 2175. Answers ranged from negligible damages to 35% of GDP (see Table 6.7).

[Table 6.8]

In addition, warming on this scale could trigger some of the catastrophic (low probability - high impact) results sometimes mentioned. These are treated in the following section.

6.4 Climate Catastrophes and Surprises

The discussion so far has focused on the impact of the best-guess climate change and some reasonable upper and lower bounds in the next century (Section 6.2) and on the longer term (Section 6.3). This section makes some statements on the impact if all climatic dices roll the

wrong way, i.e., if the enhanced greenhouse effect leads to rather unlikely but possible changes. Where some information on the physical mechanisms is available these changes are referred to here as climate catastrophes, and surprises otherwise. Also, the impact of, say, best guess could be far more dramatic than generally believed. The second part of this section briefly discusses impact catastrophes and surprises.

Most attention will be paid to the catastrophes as surprises are by definition unknown. Collard (1988) distinguishes between weakly and strongly catastrophic risks. The former category refers to the case in which the product of the likelihood of an event multiplied by its consequences tends to zero as events become more and more disastrous, i.e. the probability of the event declines more rapidly than its impact grows. A strongly catastrophic risk describes the converse situation, where the severity of an event rises more rapidly than the probability of its occurrence declines. Which category best applies to climate change risks is unclear (Tol, 1994b).

Three main types of climate catastrophes are identified in the literature, all associated with strongly non-linear responses to changed forcing: (i) the runaway greenhouse effect, (ii) disintegration of the West-Antarctic Ice Sheet, and (iii) structural changes in ocean currents. These three categories have a small but unknown possibility to occur.

The runaway greenhouse effect refers to the scenario in which one or more of the positive feedbacks dominate the negative ones such that the climate changes much more and much faster than the common consensus indicates. The main causes are a rapid increase in the natural emissions of greenhouse gases, e.g., through methane and carbon dioxide releases from melting permafrost or methane clathrates, a shutdown of major greenhouse gas sinks, e.g., through reduced plankton activity or the reduction of growth or die-back of forests, and changes in atmospheric chemistry. The runaway greenhouse effect does not only bring much larger and faster climate change, it also considerably enlarges the possibility of other catastrophes and surprises. The disintegration of the West-Antarctic Ice Sheet refers to a rapid melting of this ice-sheet, which could be unstable, leading to an additional sea level rise of 5 to 6 metres (Revelle, 1983) within the next century, causing large land losses along coastlines and inundating many low lying islands (Schneider and Chen, 1980). Changes in ocean currents have more regional impacts. The Gulf Stream transports energy from the tropics to Western Europe thereby being responsible for its moderate climate. This 'conveyor belt' is driven by temperature contrasts and salinity near Iceland. Reconstructions of past climates (Dansgaard *et al.*, 1989) and model experiments (Manabe and Stouffer, 1993) reveal that the energy transport can be weakened, start to fluctuate or even stop completely, possibly as a result of global warming. This would lead to a sharp drop in European mean temperatures.

Rapid climate change brings forward the impact of long-term warming (see section 6.3), leaving less time to adapt and thereby increasing the impact enormously. Table 6.8 provides an illustration of the possible impacts of a 10°C increase in the global mean temperature (4 times the temperature rise associated with 2xCO₂), and suggested that this might lead to about a sixfold increase in the costs compared to a 2.5°C rise. This figure cannot readily be applied to a 10°C temperature rise at the shorter term, though, since the estimates assume a moderate level of

adaptation. Adaptation will be much less successful in the case of rapid climate change. Section 6.1.6 states the power of adaptation, preventing the larger part of the losses due to sea level rise in the OECD, and mitigating agricultural losses at a moderate cost. This adaptation cost is likely to be much higher for fast or sudden changes, and some measures might be impossible to implement. The long-term figure stated above thus at best represents the lower bound of the actual costs of a catastrophe.

Unfortunately, few attempts exist to quantify catastrophic impacts directly. One exception is Tol (1994b) who splits the damage costs of climate change *inter alia* into those due to the rate of change and those due to the change compared to present temperatures. The damage module of his model FUND yields tangible damages of 0.33%, 0.55% and 1.09% of Gross World Product for a 2.5°C warming in 2095, 2057 and 2031, respectively. However, no figures on a more rapid temperature increase are reported there. The ICAM2 model (Dowlatabadi and Granger, 1993) also considers the pace as well as the amount of warming in the damage cost functions, but explicitly adds adaptation. A warming of 8°C at high latitudes and 2.8°C at low latitudes would lead to tangible losses of 6.0% of GDP in the industrialised countries and 6.6% of GDP in the less industrialised countries (Kandlikar, 1994). Nordhaus' (1994a) poll of experts provides the most direct information: a doubling of the warming by 2090 from 3°C to 6°C almost triples the costs of global warming. The probability of an impact catastrophe (i.e. damages greater than 25% of GNP) could also be considerable. The average probability stated in the survey varies between 4.8% and 17.5%, depending on the underlying warming scenario (see Table 6.7). Interestingly, natural scientists were again far more pessimistic in their assessment than economists (see also Section 6.2.15).

Even less is known about impact catastrophes compared to climate catastrophes. The upper bound damage in the Nordhaus' (1994a) survey is 20% of gross world product for a temperature rise of 3°C by the year 2090. Such a high loss could be brought about by strong non-linearities in the damage due to climate change, for instance through rapid deterioration of agriculture due to drought, floods or pests, rapid loss of species, rapid spread of vector-borne diseases, collapse of the financial sector, large scale migration, and armed conflict. The last two categories are more likely, should either of the other ones occur. Impact catastrophes are more likely to occur on a regional scale. Their valuation therefore raises questions of equity and damage aggregation (see Box 6.1): catastrophic impacts, even if limited to certain regions, may be considered undesirable from an equity point of view. The notion of possible catastrophes is particularly profound with advocates of the sustainability approach and the precautionary principle.

6.5 Regional Implications of Global Warming Damage

6.5.1 Regional Damage Estimates

Section 6.2 surveyed the available literature on comprehensive damage estimates of global warming. These are heavily biased toward the USA and to a lesser extent Europe, due to the concentration of work there. This section looks at case studies available for other regions.

Focusing mostly on agricultural impacts and sea level rise, regional studies predict impacts ranging from slightly beneficial to truly catastrophic. It is difficult to compare studies across regions, though, due to different underlying assumptions in the GCMs used, the nature of the model runs (transient or equilibrium), the models' capabilities for simulating control conditions for the relevant country (e.g. precipitation), and differences in assumptions and scenarios. Some scenarios include assumed adaptation measures, others do not. Moreover, few studies examine interlinkages between areas, so that they are not truly integrated assessments.

6.5.2 Japan

In terms of *agriculture*, research has focused on the effects of climate change and increased CO₂ on rice production (Nishioka *et al.*, 1993). Laboratory experiments with increased CO₂ concentrations (a rather high 700 ppm), produced grain yield increases of 23-71%.

An increase in effective accumulated temperature (EAT) in most of the country (except parts of Hokkaido) would reduce the vulnerability of rice to cool summer weather in the North of Japan, perhaps stabilising production. Rice producing regions may themselves be extended. Commercial rice cultivation in Japan could shift northward by 200-500 km by the end of the next century. In the north, 2xCO₂ conditions could open up most of the land below 500m altitude for rice cultivation. Currently most cultivated areas are at elevations below 200m. In light of the altered climate predicted by the GISS model, the transplanting date of rice would be advanced by 20-30 days and the maturing period would be reduced by 25-50 days. For spring wheat and winter wheat respectively, the heading date would advance by 2-5 days and 30 days, and the maturing period would reduce by 3-5 days and 3-6 days. For *forests*, some replacement of the understorey is expected due to inability of forests to migrate in the short term.

Japan's economic activities are concentrated along the *coast*. Major cities like Tokyo, Osaka and Nagoya are all located in the coastal zone. Together the three cities account for more than 50% of Japan's industrial production. Already now, about 860 km² of coastal land is below mean high water level, an area supporting 2 million people and 54 trillion yen (\$450 billion) value of physical assets. For a 1 metre rise in sea level this area would expand by a factor of 2.7 to embrace 4.1 million people and assets worth 109 trillion yen (\$908 billion). The same sea level rise would expand the flood prone area from 6270 km² to 8,900 km², with an additional 3 million people at risk (Nishioka *et al.*, 1993). Coastal protection will be central to the country's response strategy. The costs of adjusting existing protection measures has been estimated at about \$80 billion. However, extensive coastal protection would put additional pressure on Japan's remaining natural shorelines (IPCC, 1992b).

6.5.3 Africa

Very little work on impact assessment in Africa has been done. Magazda (1991) predicts reduced precipitation in the rain forests of Zaire and Uganda under doubled CO₂ concentrations. Citing Cummings on general relationships between precipitation and herbivores, Magazda predicts reductions in large herbivores as Savannah productivity is reduced, affecting buffalos and

elephants among others. Shallow lakes, such as Lake Abiata in Ethiopia and Lake Turkana in Kenya, and savannah wetlands are likely to be reduced, affecting resident wildlife and bird migrations.

Ominde and Juma (1991) emphasise the greater vulnerability of Africa to climate change due to the high *agricultural* dependence and the limited capacity for adaptation. For Egypt, Rosenzweig *et al.* (1993) predict aggregate yield losses in the order of 25-50% for 2xCO₂. The implications of agricultural damages on consumer welfare in Africa are expected to be negative even in the most optimistic scenarios (Reilly *et al.*, 1994).

Sea level rise is predicted to affect some 20% of Egypt's 35,000 km² of arable land. A 1 metre rise in sea level could destroy up to 25% of the Nile Delta's agricultural land and displace about 8 million people. Cotton and rice would be the main crops affected (El-Raey, 1990). Awosika *et al.* (1990) estimate that sea level rise would greatly exacerbate existing erosion at Lagos Beach in Nigeria, whilst even a modest rise will affect mangroves and wetlands which support timber and fishery industries. In the absence of protection a 1 metre rise in sea level could flood over 18,000 km² of Nigeria's land, damaging assets currently worth at least \$18 billion, including much of the country's oil industry which is mostly located near the coast. In addition, over 3 million people would have to be relocated. Protecting at least the highly developed areas would cost \$550-700 million (IPCC, 1994, 1992b). A similar case study for Senegal estimates that in the absence of protection over 6,000 km² of land would be lost under a 1 metre rise, some 3% of the total area. Two thirds of the population and 90% of the industry are located in the coastal zone. Protecting these areas would cost \$250-850 million, about three quarters of which would go toward beach nourishment (IPCC, 1994, 1992b).

6.5.4 Bangladesh

Climate change impacts in Bangladesh were analysed in detail in the context of a multi-country study on climate change in Asia (Asian Development Bank, 1994). Taking the coastal zone of Bangladesh to be defined by districts with a maritime boundary, the zone is a delta of the combined Ganges-Jamuna-Meghna river system and accounts for some 22% of the total land area and 16% of the population (Asaduzzaman, 1994). It also accounts for 24% of agricultural value added, 40% of manufacturing fixed assets and 22% of manufacturing employment. A 45 cm rise in sea levels (SLR) along the Bay of Bengal coast would submerge some 15,700 km² of land (about 11% of the total land area), including some 75% of the Sundarban mangrove forests. Several ports would also be affected. A 1 metre rise would affect nearly 30,000 km² (about 21% of the land area) (Asaduzzaman, 1994). This is somewhat higher than earlier estimates by the Commonwealth Secretariat (1989) which predicted a loss of just under 16% of total land area for a 1 metre rise. 1 metre sea level rise would result in all the Sundarban mangrove forests disappearing. Sea level rise will result in saline intrusion further inland than the existing freshwater-saline water interface. Changes in cyclone frequency appear to be small and soil erosion effects appear to be unknown.

Impacts on *agriculture* remain difficult to predict. A study by the Bangladesh Institute of

Development Studies suggests losses of rice output due to sea level rise as shown in Table 6.9.

[Table 6.9]

Asaduzzaman (1994) suggests that the overall macroeconomic impact of sea level rise would amount to some 30% of current GNP in the coastal zone, or some 5% of overall Bangladesh GNP. Damages in absolute terms would be perhaps \$4.8 billion in terms of 'lost' output in 2070.

The loss of the Sundarbans would impose a particularly severe loss on the poorest people of Bangladesh, relying as they do on the mangroves for fuelwood, timber, fish and many raw materials. Biodiversity losses are incalculable due to the extensive lack of knowledge about the ecological functioning of the Sundarbans. Many shrimp fisheries are likely to disappear, offset to some extent by the emergence of new estuarine fisheries as sea levels rise. Salinisation will also affect industries relying on freshwater intakes, including electricity generating plants, raising costs of production. Other industries would have to move and some would be irretrievably lost, e.g. those relying on shrimp processing. Road and rail links between Dhaka and Chittagong/Khulna would be disrupted by sea level rise, seriously affecting all international trade. Asaduzzaman (1994) suggests that 45 cm sea level rise would affect 195,000 jobs and some 790 km of roads; 100 cm rise would affect 735,000 jobs and 1460 km of roads.

Population displacement would be dramatic if impacts are assumed to be 'sudden'. Some 5% of people would be displaced by 45cm rise, and 13.5% for 1 metre rise, i.e. in terms of projected 2070 population 12 million and 32 million people, respectively. In practice, migration away from the likely to be affected areas is already taking place, partly for weather-related reasons.

6.5.5 India

A broad analysis of climate change impacts in India has been provided as a part of two multi-country studies on climate change in Asia, commissioned by ADB (1994) and SAARC (1992). Some 70% of India's annual rainfall occurs in the June-September monsoon season. Chakraborty and Lal (1994) project increases in precipitation in most parts of India due to doubled CO₂ concentrations. The Central Plains and East Coast might expect pronounced increases in annual average precipitation (1 mm/day) and this may be 2 mm/day in the monsoon period in the former region. 2 mm/day is also estimated for West Bengal in the pre-monsoon season. Monsoons thus intensify for many regions and more frequent heavy rainfall events are predicted.

In agriculture, yields may be lowered due to the decrease in the number of growing degree days due to enhanced temperatures. Seshu and Cady (cited in SAARC, 1992) suggest a decline in rice yields of 0.7 t/ha for an increase in minimum temperature from 18°C to 19°C, a decrease of 0.4 t/ha for 22 to 23°C and 0.04 t/ha for 27 to 28°C. As for wheat, it has been estimated that each 0.5°C increase in temperature would reduce productivity in Punjab, Haryana and Uttar Pradesh by about 10%. In Central India, where productivity is lower, the decrease would be

lower (SAARC, 1992). In comparison, the global study by Rosenzweig *et al.* (1993) predicts changes in aggregate agricultural yields of +3% to -33% under 2xCO₂ (including CO₂ fertilization).

Sea level rise will affect many regions, with the Andaman and Nicobar islands and the coral atolls of the Lakshadweep archipelago being among the most vulnerable areas. The east coast would be more subject to storm surges than the west coast. The western coastline south of 12° North is likely to become more eroded. No overall estimates of macroeconomic impact are available, though. In a case study of the Orissa and West Bengal region, IPCC (1992b) estimated that in the absence of protection a 1 metre sea level rise would inundate an area of 1,700 km², predominantly prime agricultural land, and displace 700,000 people. Protecting the area would require the construction of an additional 4,000 km of dikes and sea walls.

The Asian Development Bank country study for India (ADB, 1994) reports estimates by Asthana (1993) of the costs of 1 metre sea level rise for India. In the absence of protection, approximately 7 million people are estimated to be displaced, some 5,763 km² of land would be lost, and some 4,200 km of roads would also be lost. The dominant cost is land loss which accounts for 83% of all damages. While the annuitised cost is reported to be 0.18% of GNP it appears to be net of the value of land loss. Inclusive of land loss, the correct percentage appears to be 1% of GNP.

6.5.6 Indonesia

Based on calculations by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the ADB country study for Indonesia (Asian Development Bank, 1994) predicts an increase in mean annual temperature in Indonesia of 1.5°C (0.4-3.0°C) by 2070 under baseline conditions. Sea levels could rise by 45cm (15-90cm). In comparison, Parry *et al.* (1991) suggest that 2xCO₂ could raise the mean annual temperature by as much as 3°C and produce a rise in sea levels of 60 cm. Precipitation under 2xCO₂ is likely to decline in some regions, but might generally increase. Increases in rainfall could lead to a 30% increase in the irrigation area of Brantas and Citarum Basins in western Java. Soil erosion might increase by 14, 18 and 40% in the Citarum, Brantas and Saddan watersheds, with resulting soybean production losses of 2,000 to 2,700 tonnes in each region.

Enhanced temperatures and, at certain sites, reduced water availability could reduce rice yields, especially for early season rice. This could be offset to some extent by increases in late season rice. Net yields might decline by 4%. Soybean production might decline by around 10%, largely due to lower yields in the early season. Appropriate adaptive measures may lead to productivity increases which could offset potential losses, though, and overall yields may increase. The biggest yield effects are likely to be on maize output with declines of 25-65% (Parry *et al.*, 1991).

Indonesia is the world's largest archipelagic state, with nearly 17,000 islands and a shoreline of approximately 81,000 km (ADB, 1994). Sea level rise will affect coastal ecosystems, industrial

production and agriculture alike. In the Krawang and Subang districts, 95% of the predicted reduction in local rice supply (about 300,000 tonnes) and half of the loss in maize output is due to the inundation of coastal land. As a consequence, over 81,000 farmers may lose their source of income in the Subang district alone, and about 43,000 farm labourers could lose their job (Parry *et al.*, 1991). Under the baseline assumption of a 15 - 90cm sea level rise by 2070, and assuming that the Indonesian population will stabilise between 2030 and 2045, ADB (1994) predicts that about 3.3 million people will be displaced. Some 800,000 households would have to be relocated at a cost of \$ 8 bn. In the absence of protection, a total area of 3.4 million hectares could be inundated.

Indonesia is one of the few countries for which tentative *health* impact estimates are available. ADB (1994) expects that the incidence of malaria could increase by about 20%, from 2,700 cases per 10,000 people in 1989 to 3,200 cases in 2070. The incidence of diarrhoea and dengue fever could each increase by as much as a factor 3 or 4. The resulting increase in health expenditures for all three diseases could amount to \$9 million per 10,000 people (excluding the costs of death and disrupted livelihoods).

6.5.7 Malaysia

The expected impact of $2\times\text{CO}_2$ on annual mean temperature in Malaysia ranges from 1-2°C (ADB, 1994; for carbon equivalent doubling) to 3-4°C (Parry *et al.*, 1991). Rainfall increases are likely in January-February in the coastal regions of Sarawak, and in March-May in Southwestern Peninsular Malaysia. Runs of the CERES rice model predict a 12-22% yield decline for rice in the largest rice growing region of Muda. A 10% reduction in solar radiation in the Serdang region could result in maize production losses of about 20%. Rainfall increases in March-May could increase oil palm productivity in alluvial coastal areas. Temperature and rainfall changes on the eastern coast of Malaysia could make the area too wet for rubber cultivation. Roughly, rubber yield is inversely proportional to total annual rainfall. A 10% increase in rainfall could reduce yields by 13%, a figure which could rise to 25-40% due to interference with tapping (ADB, 1994). Dry marginal rubber cultivations, for example in the northern states, may become uneconomic due to drought. National yield levels could decline by 15%, but improved varieties could more than offset this loss.

The frequency of peak discharges in the Kelantan river basin in NE Peninsular Malaysia could increase by 9% under $2\times\text{CO}_2$, implying more *flood damage* and a 5% increase in the population affected by floods. About 3 million people currently live in flood prone areas. In terms of flood occurrence, the present once-every-50-year flood would return every 30 years (ADB, 1994). Water deficits in the dry season, on the other hand, are likely to increase due to higher evaporation, reducing water availability for irrigation.

About 70% of the total population of Malaysia live in the *coastal zone*, which is also the centre of most of the country's economic activities. In addition, important natural ecosystems are located along the coast, with 44 of the 1000 islands being designated as marine parks. Sea level rise could have significant consequences for the low lying coastal plains of Malaysia. Parry *et*

al. (1991) report that a 1 metre rise could lead to a landward retreat of the shoreline of as much as 2.5 km. Midun and Lee (1989) suggest that such a rise could result in the near-total loss of existing mangroves with little chance of inland migration, in particular mangrove islands. Mangrove forests are already under severe stress from human interference. Sea level rise thus aggravates an already urgent environmental problem.

6.5.8 Thailand

Parry *et al.* (1991) suggest that $2\times\text{CO}_2$ could result in a 3-6°C mean annual temperature change in Thailand, probably a rather high estimate. GCM predictions for rainfall diverge, but generally show a reduction under the GISS scenario. Northern Thailand will tend to be drier in most months except July. For Ayuthaya Province, the GISS model predicts rainfall reductions in August-September but other models do not produce this result. With respect to agriculture, preliminary runs using current climate data with the CERES agricultural model for the Ayuthaya province showed higher yields for transplanted and lower than expected yields for direct seeded rice in comparison to observed values. Under the $2\times\text{CO}_2$ climate, rice yields in this province would generally increase. The analysis suggested an 8% increase in cultivation in the province, substantially less than the currently observed year-to-year fluctuations. Off-season rice showed average yield increases of 5%. Model validation is weak, however, and the results should be treated with caution. Results for Chiang Mai, for example, suggest average yield reductions of 5%.

For the Suratthani province in Southern Thailand, a case study calculated that 37% of the area would be affected by a 1 metre *rise in sea level*, with losses of over 4200 ha of agricultural land and many shrimp ponds (Parry *et al.*, 1991).

6.5.9 Latin America

IPCC (1992b, 1994) summarises *sea level rise* case studies for several Latin American countries, including, Argentina, Uruguay and Venezuela. In Argentina a 1 metre sea level rise would inundate an area of about 3,400 km² (0.1% of total area). Erosion would claim assets and land worth \$5 billion. Venezuela could lose about 5,700 km² or 0.6% of its area under a 1 metre rise (assuming no protection). Particularly at risk would be the country's low lying coastal plains and deltas. While only a small area would be at risk in Uruguay, the coastlines affected would be highly valuable tourist beaches. Uruguay's tourist industry creates over \$200 million in revenue per annum, and attracts over 1 million visitors each summer. Protecting the beaches would be expensive. The capital costs of developed areas protection (mainly beach nourishment) were estimated at \$2.9-8.6 billion, more than five times the costs expected for Venezuela. If spread over 50 years, this would correspond to annual investments of 6-19% compared to 1987 gross investments (Nicholls *et al.*, 1992).

The impacts of climate change on *agriculture* are less well studied. Using climate analogues Magalhães and Glantz (1992) illustrate the consequences of climate extremes on Brazilian agriculture and society. In the semi-arid Northeast of Brazil, agriculture is characteristically

vulnerable to droughts. Drops in agricultural production cause mass unemployment in the agricultural sector, followed by malnutrition and hunger. Increased migration to urban centres is one of the consequences. In the global agricultural model of Rosenzweig *et al.* (1993), yield impacts in Brazil are among the most severe of all regions. Under $2\times\text{CO}_2$ yields are expected to fall by 17-33% with CO_2 fertilization, and 38-53% without. Similar reductions are also reported for Uruguay.

6.5.10 The Small Island States

The small island states (SISs) are self-evidently vulnerable to *sea level rise*. Table 6.10 summarises the results of computing a vulnerability index for different categories of countries. Vulnerability is defined in terms of exposure to foreign economic conditions (export dependence); insularity and remoteness; and proneness to natural disasters. In the full list for 113 countries, 9 out of the 10 most vulnerable countries are island states (Briguglio, 1993).

[Table 6.10]

Pernetta (1989) suggests a ranking of SISs in the Pacific in terms of their extreme vulnerability to sea level rise. 'Profound impacts', including non-existence in the worst cases, could be felt by Tokelau, Marshall islands, Tuvalu, Line Islands and Kiribati; severe impacts resulting in major population displacement would be experienced by Micronesia, Palau, Nauru, French Polynesia, Cook Islands, Niue and Tonga; moderate to severe impacts would be felt by Fiji, American Samoa, New Caledonia, Northern Marianas and the Solomon Islands; and local severe to catastrophic events would be experienced by Vanuatu, Wallis and Futuna, Papua New Guinea, Guam and Western Samoa.

Pernetta (1992) outlines various impacts that SISs may suffer. These include increased frequency of tropical cyclones in areas not normally affected by them; increases in altitudinal vegetation zones, affecting alpine grasslands in Papua New Guinea and threatening mid-montane rain forests as they come under pressure for cultivation; some increased capillarity in limestone soils, reducing soil fertility in some areas; some increases in disease due to drier conditions in some countries and longer wet seasons in others; increases in humidity and hence human discomfort and adaptation costs. Sea level rise will also affect *agriculture* since most agriculture occurs on the coasts. Agriculture will be pushed inland on to less suitable soils, increasing erosion. Exclusive economic zones based on outlying islands will be affected as some of the islands are submerged. Protection measures are limited and expensive. For the Marshall Island, for example, IPCC (1992b) reports that protecting the Majuro atoll alone would cost 1.5 to 3 times the present GDP.

Since many hermatypic corals are growing at their limit of thermal tolerance, any rise in sea water temperature could result in increased coral bleaching, with consequent loss of coral fishery resources and tourism. Although the reactions of corals to such changes appear not to be known in any detail, consequences could be significant. In the Maldives, for example, dependence on the corals is high: they are mined for building materials while fish and marine products account

for most of the island's exports. *Tourism* based on the corals is also vital. Coral deaths have already occurred probably due to increased lagoon temperatures, but pollution is also implicated.

6.5.11 Conclusions on Regional Impacts

Economic analyses of damage to developing countries from climatic change remain limited. Nonetheless, the preceding overview supports the general finding of the broader economic studies by showing that impacts on developing countries are likely to be more severe relative to the wealth of those countries. In some cases, sea level rise alone results in dramatic impacts on the economies. Summarising studies for Bangladesh, Brazil, China, Egypt, Malaysia, Nigeria and Senegal, for example, Nicholls *et al.* (1990) suggest that 1 metre sea level rise could displace nearly 100 million people in those countries alone (with China accounting for 75% of these). This is relevant to any discussion of the equity case for controlling climate change.

6.6 From Greenhouse Damages to Abatement Benefits

There is a distinction between *global warming damage* and the *benefits of policy measures*, although the two concepts are related. In general, *the benefits of greenhouse action are at least equal to the amount of damage avoided*, that is to the extra damage which would have occurred in the absence of action. In addition, there may also be ancillary benefits which are not related to climate change (see Section 6.7). The above principal rule is complicated somewhat by the dynamic character of global warming, however.

Figure 6.2 considers schematically the development of greenhouse gas emissions and damage over time under different scenarios. Under business-as-usual, emission levels are assumed to continue rising over the next 100 years or so (curve labelled "baseline" in the emissions chart). Global mean temperature levels will therefore rise as well, and so, too, will the level of global warming damage (including the influence of adaptation, see Section 6.1.7). The upper curve in the damage chart shows how annual damages may rise in the baseline. The estimates of benchmark warming damage of Section 6.2 relate to only one particular point on this time path: the point $t_{2\times\text{CO}_2}$, when the warming assumptions underlying the estimates are realized. In a business-as-usual scenario, this may for example be in the year 2060. If damage levels grow in proportion to GNP and assuming the earlier assessment is correct, damage at time $t_{2\times\text{CO}_2}$ will be in the order of 1.5 - 2.5 % of Gross World Product (GWP) (abstracting from possible differences between transient and equilibrium damage). Before this date, annual damage levels (relative to GNP) are lower. In subsequent decades they are higher, due to the rising atmospheric concentration.

[Figure 6.2]

The $2\times\text{CO}_2$ benchmark is contrasted with the consequences of a particular greenhouse gas abatement strategy, say a stabilisation of emissions at time t_0 (represented by the lower emission and damage curves). Due to the thermal inertia of the climate system, annual damage levels will

react only gradually to this policy change, and will initially continue to grow unabated. Eventually, however, damage will start to deviate from the baseline. To which level the trajectory will converge in the long run is unclear, and depends on the exact character and source of the damages.

What, then, are the benefits of the stabilisation policy? They are represented by the shaded area in Figure 6.2, which depicts the difference in annual damage levels between business as usual and the control scenario, summed up over the relevant time horizon. In each future time period damage is lower than it would have been otherwise, and the benefit of greenhouse gas abatement is the (discounted) sum of these avoided future damages.

As Figure 6.2 makes clear, there is thus no direct connection between *damage associated with $2xCO_2$* and the *benefits of greenhouse gas abatement*. The benefits of abatement occur as a *stream* of reduced damage over time, while $2xCO_2$ concerns only one point. Annual damage reduction levels will generally not coincide with the $2xCO_2$ assessment either, for two reasons: firstly, because even the most stringent abatement scheme is unlikely to succeed in avoiding all damage - some damages have already been done, i.e. they are irreversible; secondly, because damage reductions will chiefly concern years in which the business as usual damage would not be that of $2xCO_2$.

Despite this difference, $2xCO_2$ assessments still provide some indication of the size of abatement benefits. For a more precise assessment much more information would be necessary, though. A careful analysis would in particular require a better knowledge about the *slope* of the damage trajectory, that is about how global warming damage alters over time, as a consequence of both climate change and economic and population growth. A further need would be information about the degree of damage which can be avoided through a particular policy measure, that is the distance between the two damage trajectories of Figure 6.2. The answer here depends chiefly on the exact character of impacts - whether they are reversible or not, whether damage depends on the rate of change or on absolute temperature levels, whether damage is persistent or a transitional adjustment cost, and so on.

Knowledge about damage beyond the $2xCO_2$ benchmark is very limited. The small literature aiming at estimating the benefits of greenhouse gas abatement relies on several rather *ad hoc* assumptions. In older studies damage costs were typically specified as a polynomial (usually linear to cubic) function of global mean temperature, calibrated around the $2xCO_2$ estimates. Damage is usually fully reversible and typically assumed to grow with GNP. More recently, studies have started to emerge which explicitly incorporate regionally diversified temperatures and sea levels, model individual damage categories (e.g. agriculture) separately, or at least distinguish between damages related to absolute temperature level and those related to the rate of change (e.g. Morgan and Dowlatabadi, 1993; Hope *et al.*, 1993; Tol, 1994a, b).

Table 6.11 provides a list of estimates of the marginal benefits of CO_2 abatement. In terms of Figure 6.2 these numbers represent the shaded area that would occur if emissions were to deviate marginally from the baseline path, say by one tonne in period t_0 , but remain unaltered

otherwise. The estimates are mostly based on models with simple polynomial damage functions. Several of them are derived from optimal control, or dynamic cost-benefit models. In these models, the marginal benefit from abatement, or the 'shadow price of carbon', is calculated as the carbon tax necessary to keep emissions on the trajectory which is considered socially optimal by the model. In other models the marginal benefits are calculated directly, as in Figure 6.2, by comparing the present value of the stream of damages associated with a certain emissions scenario to that of an alternative scenario with marginally different emissions in the base period. Estimates vary widely, mainly as a consequence of different assumptions about the discount rate. They rise over time as a consequence of economic growth and increasing concentration levels.

[Table 6.11]

Using the base case in DICE, Nordhaus (1993a, b) finds that the shadow price begins at only about \$5 per tonne of carbon in 1995, rises to about \$10 by 2025, and reaches \$21 by 2095 (at 1990 prices). Peck and Teisberg (1992, 1993a, b) find values of a similar order of magnitude. Both models assume that parameter values are known with certainty. In the case of DICE, expected shadow prices more than double, once uncertainty is added to the model. This result arises because of the skewedness in the damage distribution, which allows for low probability - high impact events (Nordhaus, 1994b). In contrast, Cline (1992b) finds significantly higher shadow prices even in the absence of uncertainty. With the discount rate set to 1.5%, his reproduction of the DICE model generates a path of shadow prices beginning at about \$45 per ton, reaching about \$243 by 2100. Other parameter specifications provide even higher values. Tol's (1994a) alternative specification of DICE yields shadow prices of \$13 for 1995, rising to \$89 for 2095.

In comparison, Fankhauser (1994b) identifies a lower and flatter trajectory for the shadow price of carbon, rising from \$20 per tonne 1991-2000 to \$28 per tonne by 2021-2030. An important source of the difference is that Fankhauser uses a probabilistic approach to the range of discount rates, in which low and high discount rates are given different weights. Conceptually this method also differs because it seeks to identify the shadow price on a basis of discounted greenhouse damages under probability-weighted scenarios of public action and inaction.

6.7 The Secondary Benefits of Abatement Strategies

The benefits of greenhouse gas abatement will not be limited to reduced climate change costs alone, but are likely to spill over to other sectors. This is a further reason why greenhouse damage is different to the benefits of greenhouse gas abatement (see Section 6.6). For example, if abatement were brought about by an environmental tax (e.g. a carbon tax), the resulting revenues could in principle be used to lower other, distortionary taxes, such as those on labour. This could lower the welfare costs of governmental revenue raising - the so called *double dividend* of carbon abatement (see Chapter 8 of this report). Efforts to halt deforestation in order to reduce the emission of CO_2 will contribute to the conservation of the world's biological diversity. Other ancillary benefits could occur in the form of local and regional air quality

improvements, a reduction in traffic related externalities like accidents or congestion, and the reduced risk of tanker accidents and oil spills. These problems are tied to global warming in that they are caused by largely the same activities, in particular the consumption of fossil fuels. Because no economical CO₂-removal technologies currently exist, attempts to limit CO₂ emissions will by and large concentrate on reducing the use of fossil fuels. A reduction in CO₂ emissions will therefore also reduce other environmental problems related to fuel combustion⁶. These effects are often called the *secondary benefits* of carbon abatement.

Secondary benefits from air quality improvements may be quite large. Table 6.12 provides estimates of benefits from reduced air pollution levels as a consequence of carbon abatement (see also Box 6.4). The estimates are not necessarily comparable since the assumed abatement policies differ from study to study, although they all roughly aim at stabilising CO₂ emissions at about 1990 levels.

[Table 6.12]
[Box 6.4]

What is the value of these emission reductions? Estimates which measure the social costs of each pollutant vary widely between regions, depending on local factors like baseline air quality standards, ecosystem vulnerability, population at risk etc. Figures may also differ because impacts caused by a combination of gases are attributed to the initial sources in different ways. A selection of illustrative results is given in Table 6.13. The average secondary benefits implied by these estimates vary widely, from about \$2 per tonne of carbon abated to over 500 \$/tC. In absolute terms secondary benefits offset about 30-50% of the initial abatement costs in the case of Norway (Alfsen *et al.*, 1992) and over 100% in the UK (Barker, 1993).

[Table 6.13]

The figures in Table 6.12 relate to Europe or the United States. Amano (1994), has extended the Alfsen *et al.* (1992) study to several Asian regions, using the same benefit-abatement ratios (air quality benefits, in percent of GDP, per percentage cut in air pollution). The Amano calculations imply that secondary benefits could be similarly important in Asian countries. However, since the study uses the Norwegian ratios results should be interpreted with caution. For Japan and India estimated secondary benefits exceed the primary costs of stabilising emissions at 1990 levels. For China and the group of "Dynamic Asian Economies" (Hong Kong, Philippines, Singapore, South Korea, Taiwan and Thailand) secondary benefits are estimated to offset about one third of the initial abatement costs.

⁶ This is not the only connection between global warming and air pollution. The two issues are heavily intertwined. For example, sulphur abatement, if achieved through the installation of end of pipe scrubbers, could lead to an increase in CO₂ emissions. The accumulation of sulphur aerosols in the atmosphere causes a reduction in global mean temperature, thus masking the extent of global warming. A warmer temperature on the other hand will aggravate air pollution.

An alternative way to measure secondary benefits is by estimating the change in the costs of meeting air quality standards. Many industrialized countries are committed to significant cuts in the emission of air pollutants. The Helsinki protocol of 1985 required a cut in sulphur emissions of 30% by 1993, compared to 1980 levels, for selected European countries. Under the 'Second Sulphur Protocol' further reductions will be required up to 2010. The Sofia Protocol on nitrogen dioxide commits signatories to a freeze on emissions at 1987 levels. Greenhouse gas abatement will lower the amount of traditional air pollution abatement needed to meet these targets. Alfsen *et al.* (1993), for example, calculate that the introduction of a carbon/energy tax would reduce the cost of traditional SO₂ and NO_x abatement in the nine countries introducing the tax by 25 - 30% and 12 - 25 %, respectively, implying average secondary benefits of about 2.5 \$/tC for NO_x and 4.0 \$/tC for SO₂. These results are low compared to the previous estimation procedure.

It is important to underline the different character of secondary benefits compared to their primary (warming damage avoidance) counterpart. Most critically, secondary benefits do not depend on climate variables but only arise in connection with greenhouse gas abatement. They occur locally or regionally and do not share the global character of greenhouse damages. The question of secondary benefits from carbon abatement should also be distinguished from the more comprehensive issue of the optimal abatement mix with respect to all pollutants. The secondary benefit argument is characterized by an implicit primacy of the greenhouse problem, in that improvements in other areas are seen as welcome side effects of a global warming policy, but are not considered or sought in their own right. This is not necessarily the ideal way to proceed. Strictly, each pollutant should be taxed in proportion to the environmental damage it causes. If there are interdependencies between them, as is the case with global warming and air pollution, these would have to be reflected in the relative tax rates. The currently considered abatement strategies may then no longer constitute the optimal approaches. Once secondary benefits are taken into account, *location* will also matter. Unlike for greenhouse gases, for most other air pollutants it matters where they are emitted. Emission reduction measures should therefore be concentrated to those places where the joint benefits of reducing all emissions is highest.

6.8 Summary and Conclusions

This chapter has been concerned with the measurement of global warming damage and with the benefit of policies designed to reduce this damage. Climate change impact assessments are an integral input to benefit-cost studies and other decision making frameworks (see Chapters 2 and 5). Economic models comparing the costs and benefits of greenhouse gas abatement are discussed in Chapter 10 on integrated assessment.

Social cost estimates are necessarily *uncertain*. Apart from the scientific uncertainty of climate change, there are additional uncertainties associated with:

- (a) limited knowledge of regional and local impacts;

- (b) difficulties in measuring the economic value of impacts, even where the impacts are known. This is particularly the case for non-market impacts and the impacts in developing countries;
- (c) difficulties in predicting future technological and socio-economic developments;
- (d) the possibility of catastrophic events and surprises.

This uncertainty must be emphasised when interpreting the social cost figures in this chapter.

Most global warming impact analysis has concentrated on the case of $2\times\text{CO}_2$, a doubling of atmospheric CO_2 concentration levels. The available studies estimate damages for $2\times\text{CO}_2$ concentration as follows:

World impact: 1.5 - 2.5% of world GNP
 Developed country impact: 1 - 2% of GNP
 Developing country impact: 2 - 9% of GNP

These are *best guess* figures. The range does not represent the confidence interval around the estimates, but the spread of results in existing studies. No attempt has been made to quantify a confidence interval. There will be considerable differences in regional damage figures, with potentially higher impacts for some individual countries, e.g. small island states. The regional variability of the social costs underlines the important issues of equity discussed in Chapter 3.

These cost estimates are for $2\times\text{CO}_2$ concentrations. Global warming will not stop at this level of concentrations if it is unconstrained. *Long term warming* damage may rise more than linearly. The damage associated with 10°C might be 6% of world GNP or more. The probability of a climate catastrophe also increases over time.

The *marginal damage*, i.e. the extra damage done by one extra tonne of carbon emitted now, is estimated to be \$5 - 125 per tonne of carbon, with most estimates being at the lower end of this range. The value will rise for marginal emissions in later periods. The range appears wide but reflects variations in scenarios, models, discount rates etc. The numbers are particularly sensitive to the choice of the discount rate. The models on which these estimates are based remain simplistic and are limited representations of the actual processes. But they represent the state of the art at this moment.

The marginal damage of an extra tonne of emissions is not necessarily the same as the marginal benefits of abating an extra tonne. Abatement measures will yield additional benefits besides avoided warming damage. These are the *secondary benefits*, which occur for example in the form of local air quality improvements. The size of secondary benefits depends on local circumstances. Studies for European countries and the United States indicate that secondary benefits could offset between 30 and 100% of abatement costs. Whether the benefits of climate policies are high enough to justify the costs of abatement is an issue addressed in Chapter 10.

Box 6.1: Attributing a Monetary Value to a Statistical Life

Attributing a monetary value to a 'statistical life' is controversial and raises a number of difficult theoretical and ethical issues. It is important to understand that what is valued is a change in the risk of death, not human life. It is a *statistical life* that has an economic value. It would make no sense to ask an individual how much he or she is willing to pay to avoid certain death. Nor is that the context of social decision-making. But it can make sense to ask what individuals are willing to pay to reduce the risk of death, or what they are willing to accept to tolerate an increased risk of death.

The reality is that human life is not 'beyond price'. If it were, most of the world's wealth would be spent trying to save lives by reducing accidents and preventing disease. Risks are taken every day, both voluntarily by individuals and by governments in choosing their social and economic expenditures, some of which are specifically directed at protecting and extending human life. For example, if a government introduces a programme of inoculation for childhood diseases that costs \$10,000,000 per year and saves an average of 80 lives per year, a statistical life is implicitly valued at \$125,000 at a minimum.

Several methods have been applied to calculate the value of a statistical life (VOSL). None of them is without problems.

The Prescriptive View

From a *prescriptive* or normative point of view, ie if the question is at how much a statistical life ought to be valued, it seems evident that all lives should be treated equally. Each statistical life saved should have the same value. However, the question of what this uniform value should be is extremely difficult to answer from a purely prescriptive point of view. In the context of global warming it has been argued that the rich countries have caused the global warming problem, and that the polluter-pays-principle therefore dictates the use of a rich-country VOSLs for all lives. An example of such an approach is given by Hohmeyer and Gärtner (1992). One implication then is that mortality damage is the dominant climate change impact in developing countries, as is the case with the Hohmeyer and Gärtner estimates.

The alternative is to take a *descriptive* stance and ask how much people are actually willing to spend to avoid the risk of death. Most studies that attempt to estimate damage due to climate change (see Table 6.4) are based on a descriptive perspective. Two approaches are commonly used in the economic literature: the human capital approach and the willingness to pay approach.

The Human Capital Approach

The human capital method involves treating an individual as an economic agent capable of producing an output that is valued in monetary terms. A life lost is then the loss of that output,

less any consumption that the individual would have made. One immediate problem with the approach is that, if it is applied literally, the very old would have negative values for their lives - they would not be contributing to output, but they would be consuming. Moreover, it tends to produce extremely low values for those with low earnings, clearly discriminating against the already poor. As with many other valuation procedures, it is then often the value of a statistical life at a mean or median age or income group that is applied 'across the board'. The main problem with the human capital approach is that it has no particular relationship to an individual's willingness to pay to reduce his or her risks of mortality. It is not properly founded in economic theory.

The Willingness to Pay / Willingness to Accept Method

The theoretically preferred approach is to value a statistical life on the basis of what individuals are willing to pay or accept for risk changes. Such values can be based on methods such as *contingent valuation*, where individuals are asked directly how much they would be willing to pay to reduce risks. Other measures include finding out what people are willing to pay to adopt safety and disease preventing measures. For willingness to accept, the *hedonic wage approach* can be used. For example, if there are 100,000 workers and each is willing to accept \$15 to tolerate an increased risk of mortality of 1/100,000 then the increased risk will result in one statistical death. The value of that statistical life is then $\$15 \times 100,000 = \$1,500,000$.

One problem with the willingness to pay approach is that it relies on individuals having a reasonably adequate perception of the risks undertaken. Arguably this is not always the case, particularly in developing countries. Another disadvantage of the WTP approach is that the resulting figures depend on factors which may be distributed in a way which is not considered just. Most importantly, the estimates depend on a person's income. Rich people are better able to afford safety expenditures, while poorer people's WTP may be constrained by their ability to pay. If the existing income distribution were 'just' or 'equitable', this would not matter. The higher WTP of the better off would simply reflect the privileged status they are granted by society. However, if the underlying income distribution is unjust, WTP estimates will reflect the discrimination against the less well off, too.

Willingness to Pay Estimates

Studies of the contingent valuation and hedonic wage risk approaches suggest VOSLs in the order of about \$1.8 - \$9 (best guess \$3.5) million in the developed world (Viscusi, 1993; ORNL/RFF, 1994). Since few studies exist for the developing world it is difficult to say what the results would be for these techniques. Since WTP is constrained by ability to pay (wealth and income) the results are likely to be very much lower. A preliminary study for India place 'own valuations' at perhaps \$120,000 (Parikh *et al*, 1994).

'Borrowing' VOSLs from developed economy studies is hazardous. Various rough and ready approaches have been tried. For example, developing country valuations could be estimated as

$$VOSL_{dc} = VOSL_{dc} \cdot (Y_{dc}/Y_{dc})^E$$

where ldc = developing economy, dc = developed economy; E either denotes the income elasticity of demand or the elasticity of the marginal utility of income, and Y is income. Developing countries' VOSLs would simply be 'scaled down' by the ratio of incomes raised to the power E . If $E = 1$, then the scaling down is simply done by the ratio of incomes. In terms of the above formula, if $E = 1$, and dividing both sides of the equation by Y_{dc} , the result is $VOSL_{dc}/Y_{dc} = VOSL_{dc}/Y_{dc}$, i.e. the VOSL in a developing country is the same proportion of income as it is in the developed economy. In the light of the existing developing country estimates, this seems a reasonable first approximation. But it still leaves the *absolute* VOSL lower in developing countries.

Aggregation

Comparing WTP estimates across regions is therefore extremely hazardous. Many would argue that interregional comparisons should be avoided altogether. If comparisons are made, figures should be interpreted with care, and measures may have to be introduced to avoid unwanted ethical implications. This is most suitably done in the aggregation process (see Box 6.2). Weights in the aggregation process could be chosen such as to correct for the injustice in the underlying income distribution, for difference in purchasing power parity, etc. This may result in changes in monetary values based on income levels as they are computed conventionally. For example, if VOSL is scaled in proportion to income, as suggested above, and aggregation weights are inversely related to income, as proposed in Box 6.2, weighted VOSLs will effectively be equal across countries.

Box 6.2 Damage Aggregation Across Countries and Individuals

Benefit-cost analysis assumes that the monetary values of damage can be aggregated across (a) individuals, and (b) countries. This aggregation process raises an important problem of so-called *interpersonal comparisons of utility*, where utility is simply another word for "welfare" or "wellbeing". Basically, introspection allows any one individual to assess his or her *own* preferences, but perhaps not *others'* preferences. Each individual knows by how much he or she is better off in situation X compared to situation Y, but he or she cannot assess how this change compares to the extent to which someone else is better off for the same change of situation. This inability to assess *other minds* produces the theorem that it is impossible to make comparisons of wellbeing between individuals, and hence by extension, between countries. There is therefore an endless number of ways in which *individuals'* assessment of their own wellbeing can be aggregated to yield a measure of *social welfare* change.

Measuring social welfare change requires interpersonal welfare comparisons, comparisons that require ethical judgements about individuals preferences. Such judgements could include one to the effect that preference measures should not be unduly influenced by income differences. In this case, the individual measures of preference - willingness to pay - could be weighted so as to reflect the preference of someone with an average income. One way to proceed is to indicate the outcomes of the benefit-cost analysis according to differing value judgements about the weights attached to preferences - a kind of "value sensitivity analysis". Thus, whether a change in the state of the world raises or lowers social welfare depends on the impacts on individual welfare as well as on normative criteria for making interpersonal welfare comparisons. Measures of social welfare change are, therefore, not objective but normative.

Global warming damage formulations usually present total damages (D) as the sum of individual impacts (d_i),

$$D = \sum_i d_i$$

Instead an alternative formulation could be to present the results in the following way,

$$D = \sum_i d_i \left(\frac{Y_a}{Y_i} \right)^E$$

where Y_a is now some reference level of income, say the global average income, or the income of the richer countries, and E is a factor correcting for differences in the utility of income between countries. In the literature, E is usually either the income elasticity of demand or the elasticity of the marginal utility of income. Other ways of determining equity

weights, e.g. using factors other than income, could of course also be used (see also Chapter 3 on equity issues).

An example will indicate how the measures differ. Suppose there are just two countries. In country A, damage d_A is \$50 and in country B it is \$30. Country A has an income of \$5,000 and in country B it is \$1,000. The unweighted approach would make the global damage \$80. As a percentage of world income this is 80/6000 = 1.33%. Note however, that A's damage is 1% of its income, and B's is 3%.

Setting Y_a at the average world income of \$3000, and E=1 for convenience, the weighted procedure would produce the following result,

$$D = 50 \cdot \left(\frac{3,000}{5,000} \right) + 30 \cdot \left(\frac{3,000}{1,000} \right) = 30 + 90 = 120$$

Damage is now in "equity weighted" terms, and expressed as a fraction of world income it is 2%. The share of B's income has risen to 9% and the effect of equity weighting is therefore to make B's damage much more important.

How is the value of E selected? If logarithmic utility functions are chosen and E is interpreted as the elasticity of the marginal utility of income, then E=1, and we have the results shown above. Various alternative weights could be chosen, e.g. to reflect income elasticities of demand.

There are many problems involved in such procedures, but they illustrate the idea of "value sensitivity". The issue of interpersonal utility comparisons has been addressed above. There is also the question of what per capita income figure to use. Here the answer is probably purchasing parity rather than exchange-rate based per capita income. For low-income countries, the former tend to be about three times as high as the latter, whereas the two are approximately equal for rich countries. The use of exchange-rate based per capita income would inappropriately increase still further the multiple of the developing country welfare weight relative to the industrial country welfare weight. Further, what is the time reference of the per capita income? In principle it should be in the year for which the damage is calculated, and thus, say, 2050 and beyond. By then the per capita income multiple of rich relative to poor nations should have diminished from more rapid growth in the latter, reducing the differences among relative welfare weights.

Consideration of welfare-weighted impacts widens the array of policy implications. In one dimension, it helps show how extreme effects for some countries might count for relatively more than minor effects summed over a larger block of countries (e.g. welfare effects for an island state expected to be inundated might be larger than would be attributed solely on the basis of its income or even population). The reason is that the marginal utility rises as per capita income declines, so that utility-based damage for one country with a 30 percent loss in per capita income is greater than the sum for five other countries of equal size but with 6 percent income reduction each. In another dimension, consideration of welfare-weighting quickly leads to recognition of gains from trade in greenhouse effects. Income available is based on country shares in global income, whereas utility effects essentially

involve population weighting. In a cooperative international abatement program, there is a resulting opportunity for efficient trades in which rich countries allocate some of their income to defray the losses of poorer countries that are equivalent in absolute terms to the income transferred but much larger in terms of utility otherwise sacrificed. Of course, this same dynamic suggests that a utility-oriented approach would counsel larger amounts of grant aid to poor countries already today, irrespective of the greenhouse effect. That such larger flows do not presently occur (they would have to completely eliminate per capita income differences to remove the gain from utility trade) is not an argument for failing to consider welfare weighting in greenhouse damage analysis, if only because there is a qualitative and ethical difference between refraining from assisting on the one hand and imposing damage on the other.

Box 6.3 Relative Damage in Developing and Industrial Countries

Various factors influence global warming damage in less developed countries (LDCs) as opposed to industrial countries (DCs), as a fraction of (purchasing-power) GDP.

- **Location:** In general, warming is expected to be greater at higher latitudes. Because the developing countries tend to be located closer to the equator, from this standpoint one would expect *lesser* impact on developing than on industrial countries.
- **Economic Structure:** Because LDCs have a much higher share of GDP in agriculture, and therefore a larger share of output directly exposed to climatic influences, one would expect a *greater* impact on LDCs than on DCs from this standpoint.
- **Coastal Vulnerability:** The incidence of coastal vulnerability to sea level rise and possible increase in tropical cyclone damage is probably *greater* in LDCs than DCs. Although vulnerable areas can be found in industrial countries (for example, Louisiana), vulnerability is particularly high for such LDCs as Bangladesh, Egypt, and China. Low-lying island states tend to be LDCs. Of 50 countries or territories identified as having shore protection costs above 0.5 percent of GDP annually as a consequence of a 1-metre rise in sea level, all but one (New Zealand) are LDCs (IPCC, 1990b).
- **Rigidities:** Capacity to adapt to warming may be more limited in developing countries. Adaptation requires an investment outlay, and low-income communities tend to have lower savings rates and flexibility to undertake these investments. Thus, Rosenzweig *et al.* (1993) identify *greater* relative damage to agriculture in LDCs, partly because crops are already grown nearer to heat tolerance limits but also because of lesser expected capacity to adapt than in DCs. A possible consideration in the other direction is that the economy growing more rapidly has a lower fraction of past fixed investment in its total capital stock, and thus easier adjustment.
- **Human Life:** Because of poorer nutrition and health infrastructure, proportionate loss of life from global warming (from heat waves, increased hunger risk, possible tropical storm damage increase) seems likely to be *greater* in LDCs than in DCs. Valuation effects could go either way. Most statistical life valuation techniques would place a lower unit value in a country with lower per capita income (see Box 6.1). However, some would question this differentiation on ethical grounds. Moreover, income-related differences would tend not to affect impacts expressed as a fraction of GDP, as the base would also be proportionately lower.

Box 6.4 Valuation of Electricity-Related Externalities in California

The importance of secondary air quality benefits can be illustrated at least in part from the practices of some regulatory commissions in the United States. A growing number of these now require that electric utilities take into account the value of air emissions in their cost-benefit analysis of alternative supply and demand side resources.

The monetary air quality values used in these assessments do not usually represent actual marginal damages, however. CO₂ values, for example, are mostly based on avoided costs, e.g. the cost of planting trees on otherwise unforested land. The environmental cost adders for the other pollutants are also mostly based on control costs. The conceptual basis for this method is rather weak: using abatement costs as a proxy for the damage costs could involve substantial error. The use of damage control costs as a proxy is justified by many regulatory commissions on the basis that damage cost estimates are themselves uncertain.

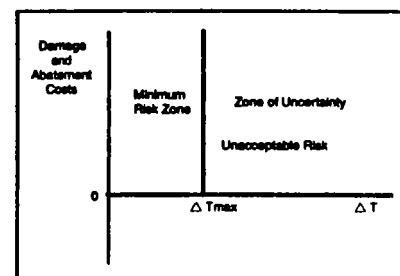
A study commissioned by the California Energy Commission which does use consistently estimated damage-cost based externality values is shown below. These estimates for the Los Angeles area imply that for every dollar in benefits resulting from the reduction of CO₂ emissions, there is another \$ 3 benefit to the area resulting from the reduction of conjoint pollutants. It is a reasonable conclusion, therefore, that joint benefits can significantly affect the overall cost-benefit assessment of climate policies.

	Environmental Benefits (\$/t)	Emission Rate (lbs/mwh)	Total Benefits (\$)
CO ₂	26 ¹	1,820	23
joint products			
NO _x	14,483	6	43
SO ₂	7,425	6	22
TSP	57,620	0.3	9
Total joint products			74

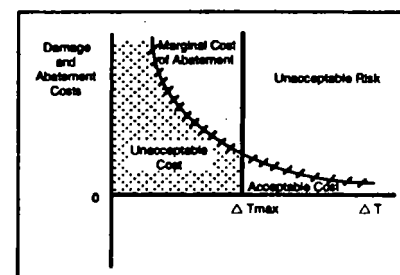
¹ benefits in the form of *avoided costs* of carbon sequestration

Source: Emission rates based on a notional, new coal-fired plant meeting new source performance standards (NSPS). Externality values for NO_x, SO₂ and particulates (TSP) are in 1989 US\$, based on Hashem and Haites (1993).

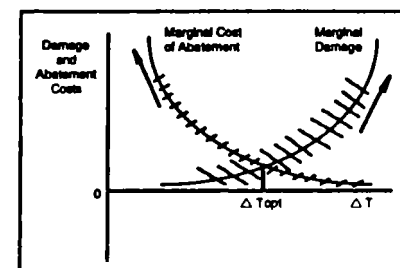
Figure 6.1 Climate Change, Cost-Benefit Analysis and Sustainable Development



(a) Absolute Standard Approach



(b) Safe Minimum Standard Approach



(c) Cost-Benefit Approach

Source: Chapter 6

9/18/05 Rps 1/95 ap

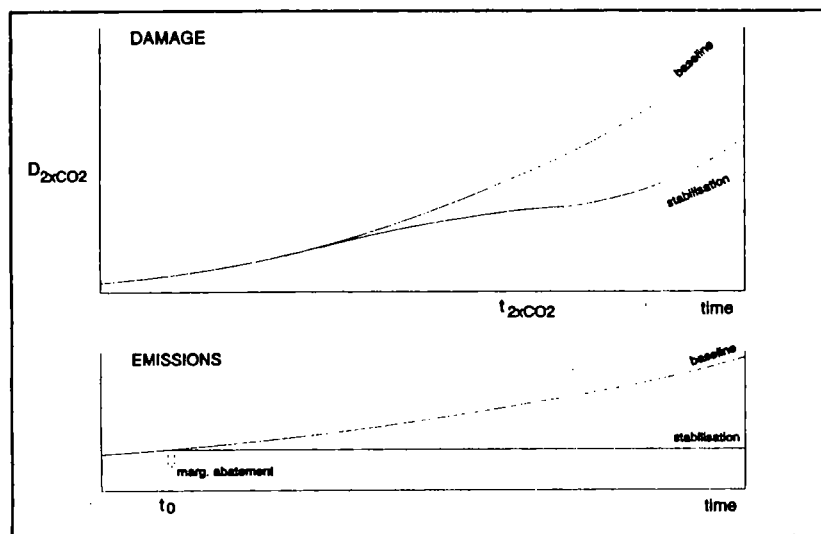


Figure 6.2 2xCO₂ Damage vs. Abatement Benefits. Under business-as-usual, greenhouse gas emissions will continue to rise over time (upward sloping line in the emissions graph). As a consequence annual global warming damages will rise over time as well (upper line in the damage graph). If instead emissions are stabilised at time t_0 (the horizontal "stabilisation" line in the lower graph), the annual damage curve will follow a more flat trajectory (the lower curve in the upper diagram). The benefit of this stabilisation policy is represented by the shaded area: the sum of avoided damages in all time periods. Stabilising emissions constitutes a significant change in policy. Analysts are often interested in the benefits obtained through only a *marginal* deviation from the baseline - the marginal benefit per tonne abated, or the marginal cost of an additional tonne of emissions. Marginal changes are conceptually calculated in the same way, as the difference in the two damage trajectories with and without the abated tonne (not drawn in the figure). The two emission paths with and without marginal abatement would be identical, except for a slight deviation at time t_0 .

Table 6.1 Overview on Climate Change Impacts

Damages	Market Impacts			Non-Market Impacts		
	Primary economic sector damage	Other economic sector damage	Property loss	Ecosystem damage	Human impacts	Damage from extreme events
Fully estimated based on willingness to pay	agriculture ¹		dryland loss coastal protect.			
Fully estimated, using approximations	forestry	water supply				hurricane damage
Partially estimated	fisheries ²	energy demand leisure activity	urban infrastructure	species loss	human life air pollution water pollution migration	damage from droughts ³
Not estimated		insurance construction transport energy supply		other ecosystems loss	morbidity physical comfort polit. stability human hardship	non trop. storms river floods hot/cold spells other catastrophes

¹ widespread disagreement
² often included in wetland loss
³ primarily agricultural damage

Table 6.2 Preference Valuation for Endangered Species and Prized Habitats

Country	Species or Habitat	Value (1990\$/year/person)
Norway	brown bear, wolf and wolverine	15.0
	conservation of rivers against hydroelectric development	59.0-107.0
United States	bald eagle	12.4
	emerald shiner	4.5
	grizzly bear	18.5
	bighorn sheep	8.6
	whooping crane	1.2
	blue whale	9.3
	bottlenose dolphin	7.0
	California sea otter	8.1
	northern elephant seal	8.1
	humpback whale ¹	40-48 (without information) 49-64 (with information)
	Grand Canyon (visibility)	27.0
	Colorado wilderness	9.3-21.2
Australia	Nadgee Nature Reserve (NSW)	28.1
	Kakadu Conservation Zone (NT) ²	40.0 (minor damages) 93.0 (major damages)
UK	nature reserves ³	40.0 (informed individuals)

¹ Respondents divided into two groups one of which was given video information

² Two scenarios of mining development damage were given to respondents

³ Survey of informed individuals only

Source: Pearce (1993).

Table 6.3 Reported Fatalities due to Weather Events 1989-1992

Region	Total Number				Average
	1989	1990	1991	1992	
Africa	31	138	> 621	> 360 > 69 ¹	> 288 > 215 ¹
Asia	> 4,300	> 3,280	> 142,000 > 3,000 ²	> 7,766 > 2,766 ²	> 39,337 > 3,337 ²
South America	> 35	26	> 117	108	> 72
Central & North America	> 75	> 57	> 86	> 131	> 87
South West Pacific	17	804	6,640 296 ³	90	1,888 302 ³
Europe	> 52	> 129	> 65	> 424	> 161
Total:					
all events	> 4,483	> 4,434	> 149,529	> 8,879	> 41,831
excl. major disasters	> 4,483	> 4,434	> 4,185	> 3,588	> 4,173

¹ Excluding the Madagascar 1992 drought and famine.

² Excluding the Bangladesh 1991 and Pakistan 1992 floods

³ Excluding the Philippines 1991 storm

Source: Limbert (1993).

Table 6.4 Economic Damages from Global Warming: Present US Economy
(base year 1990; billion \$)

	2xCO ₂				
	Cline (2.5°C)	Fankhauser (2.5°C) ¹	Nordhaus (3°C) ¹	Titus (4°C)	Tol (2.5°C) ²
Agriculture	17.5	8.4	1.1	1.2	10.0
Forest Loss	3.3	0.7	small	43.6	-
Species Loss	4.0 + a ³	8.4	4	-	5.0
Sea Level Rise	7.0	9.0	12.2	5.7	8.5
Electricity Non-El. Heating	11.2 - 1.3	7.9 -	1.1	5.6 -	- -
Human Amenity	+ b ³	-	4	-	12.0
Human Morbidity	+ c ³	-		-	-
Human Life	5.8	11.4		9.4	37.4
Migration	0.5	0.6		-	1.0
Hurricanes	0.8	0.2	-	-	0.3
Construction	± d ³	-	-	-	-
Leisure Activities	1.7	-	-	-	-
Water Supply availability pollution	7.0 -	15.6 -	-	11.4 32.6	- -
Urban Infrastruc.	0.1	-	-	-	-
Air Pollution tropos. Ozone other	3.5 + e ³	7.3	-	27.2 -	- -
Mobile Air Cond.	-	-	-	2.5	-
Total (% of GDP)	61.1 +a+b+c±d+e (1.1)	69.5 (1.3)	55.5 (1.0)	139.2 (2.5)	74.2 (1.5) ²

¹ transformed to 1990 base

² USA and Canada, base year 1988

³ identified, but not estimated

⁴ not assessed categories, estimated at 0.75% of GDP

Sources: Cline (1992a), Fankhauser (1995), Nordhaus (1991), Titus (1992), Tol (1994b).

Table 6.5 Quantitative 2xCO₂ Damages in Different World Regions (2.5°C warming)

Type of damage	Damage indicator	EU	USA	Ex USSR	China	Non-OECD	OECD	World
agriculture	welfare loss (% GNP)	0.21	0.16	0.24	2.10	0.28	0.17	0.23
forestry	forest area lost (km ²)	52	282	908	121	334	901	1,235
fishery	reduced catch (1000t)	558	452	814	464	4,326	2,503	6,829
energy	rise in electricity demand (TWh)	54.2	92.0	54.6	17.1	142.7	211.2	353.9
water	reduced water availability (km ³)	15.3	32.7	24.7	32.2	168.5	62.2	230.7
coastal protect.	annual capital costs (m\$/yr)	133	176	51	24	514	493	1,007
dryland loss	area lost (1000 km ²)	1.6	10.7	23.9	0	99.5	40.4	139.9
wetland loss	area lost (1000 km ²)	9.9	11.1	9.8	11.9	219.1	33.9	253.0
ecosystems loss	number of protected habitats lost, assuming 2% loss (section 3.2.12)	16	8	?	4	53	53	106
health/mortality	number of deaths (1000)	8.8	6.6	7.7	29.4	114.8	22.9	137.7
air pollution	equivalent increase in emissions (1000 t NO ₂)	566	1,073	1,584	227	2,602	1,943	4,545
troposph. O ₃	(1000 t sulphur)	285	422	1,100	258	1,864	873	2,737
SO ₂	additional immigrants (1000)	229	100	153	583	2,279	455	2,734
migration	number of deaths	0	72	44	779	7,687	313	8,000
hurricanes	casualties	0	115	1	13	124	506	630
damages	m\$							

Source: after Fankhauser (1995).

Table 6.6 Monetary 2xCO₂ Damage in Different World Regions

	Fankhauser bn\$	(1995) %GDP ¹	Tol (1994b) bn\$	%GDP ¹
• European Union	63.6	1.4		
• United States	61.0	1.3		
• Other OECD	55.9	1.4		
• OECD America			74.2	1.5
• OECD Europe			56.5	1.3
• OECD Pacific			59.0	2.8
<i>Total OECD</i>	<i>180.5</i>	<i>1.3</i>	<i>189.5</i>	<i>1.6</i>
• E. Europe / Former USSR	18.2 ²	0.7 ²	- 7.9	-0.3
• Centrally Planned Asia	16.7 ³	4.7 ³	18.0	5.2
• South and South East Asia			53.5	8.6
• Africa			30.3	8.7
• Latin America			31.0	4.3
• Middle East			1.3	4.1
<i>Total Non-OECD</i>	<i>89.1</i>	<i>1.6</i>	<i>126.2</i>	<i>2.7</i>
<i>World</i>	<i>269.6</i>	<i>1.4</i>	<i>315.7</i>	<i>1.9</i>

¹ Note that the GDP base may differ between the studies

² Former Soviet Union only

³ China only

Sources: as shown.

Table 6.7 Expert Opinion on Climate Change Damage

	Scenario A 3°C warming by 2090	Scenario B 6°C warming by 2175	Scenario C 6°C warming by 2090
<i>Damage Relative to World GDP (% of GDP)</i>			
mean answer	3.6	6.7	10.4
median answer	1.9	4.1	5.5
range of answers	0.0 - 21.0	0.0 - 35.0	0.8 - 62.0
<i>Probability of Damage > 25% of GNP (%)</i>			
mean answer	4.8	12.1	17.5
median answer	0.5	3.0	5.0
range of answers	0.0 - 30.0	0.2 - 75.0	0.3 - 95.0

Source: Poll of experts, Nordhaus (1994a).

Table 6.8 Illustrative Damages from Long Term Warming: Present US Economy
(base year 1990; billion \$)

	Long Term Warming (10°C)
Agriculture	95.0
Forest Loss	7.0
Species Loss	16.0 + A ¹
Sea Level Rise	35.0
Electricity	64.1
Non-Electric Heating	- 4.0
Human Amenity	+ B ¹
Human Morbidity	+ C ¹
Human Life	33.0
Migration	2.8
Hurricanes	6.4
Construction	± D ¹
Leisure Activities	4.0
Water Supply availability pollution	56.0 - -
Urban Infrastructure	0.6
Air Pollution tropospheric ozone other	19.8 + E ¹
Total	335.7 + A+B+C±D+E
(% of GDP)	(6.1)

¹ identified, but not estimated

Source: Cline (1992a).

Table 6.9 Losses of Rice Output due to Sea Level Rise in Coastal Zones of Bangladesh

Year	SLR by 2070: (1000 tonnes)	45 cm (% coastal output)	SLR by 2070: (1000 tonnes)	100 cm (% coastal output)
2020	125	2	412	4
2050	2,122	28	7,708	49
2070	2,619	28	9,514	50

Source: Asaduzzaman (1994).

Table 6.10 Vulnerability Index for Different Categories of Countries
(High vulnerability is indicated by values closer to 1)

Country Categories	Number of Countries	Index
All countries	113	0.376
Developed Countries	22	0.208
Developing Countries	91	0.417
Small Island Developing Countries	20	0.590
Other Island Developing Countries	28	0.539

Note: The index is calculated as the average value of 3 variables. Variable i for country j is calculated as $V_{ij} = (X_{ij} - \min X_i) / (\max X_i - \min X_i)$, where $\max X_i$ and $\min X_i$ denote, respectively, the highest and lowest value observed for component i, and X_{ij} the value of component i obtained for country j.

Source: Briguglio (1993).

Table 6.11 The Social Costs of CO₂ Emissions in Different Decades
(current value (1990)\$/tC)

Study	Type	1991-2000	2001-2010	2011-2020	2021-2030
Nordhaus (1991)	MC	7.3 (0.3-65.9)			
Ayres and Walter (1991)	MC	30 - 35			
Nordhaus (1994b) - certainty/best guess - uncert./ exp. value	CBA	5.3 12.0	6.8 18.0	8.6 26.5	10.0 n.a.
Cline (1992b, 1993d)	CBA	5.8 - 124	7.6 - 154	9.8 - 186	11.8 - 221
Peck and Teisberg (1992)	CBA	10 - 12	12 - 14	14 - 18	18 - 22
Fankhauser (1994b)	MC	20.3 (6.2-45.2)	22.8 (7.4-52.9)	25.3 (8.3-58.4)	27.8 (9.2-64.2)
Maddison (1994)	CBA /MC	5.9-6.1	8.1 - 8.4	11.1-11.5	14.7-15.2

Note: MC = marginal social cost study,
CBA = shadow value in a cost-benefit study.
Figures in brackets denote 90% confidence intervals.

Sources: as indicated.

Table 6.12 Reduced Air Emissions due to CO₂ Abatement
(% reduction compared to baseline)

Country	Year	Policy/Scenario	CO ₂	SO ₂	NO _x	CO	Partic.	VOC ¹	Secondary Benefits (\$/tC)	Sources
Europe ²	2000	EU carbon/energy tax - current product. structure - cost efficient regime	9.4 9.7	7.4 9.3	6.2 6.4	n.a. n.a.	n.a. n.a.	n.a. n.a.	6.1 6.6	Alfsen <i>et al.</i> (1993)
Norway	2000	Emission stabilisation (at 1989 level)	15.0	20.8	10.8	24.1	4.3	n.a.	40 - 140 ³	Alfsen <i>et al.</i> (1992)
UK	2005	EU carbon/energy tax	12.1	38.3	10.6	9.6	30.3	1.1	40 - 1040	Barker (1993)
US	2000	Emission stabilisation - through carbon tax - through Btu tax	8.6 8.6	1.9 ⁴ 2.2 ⁴	6.6 6.6	1.5 3.4	1.0/1.8 ⁵ 1.6/2.2 ⁵	1.4 2.7	2.0 - 20 3.5 - 28	Scheraga and Leary (1994)

¹ Volatile Organic Compounds

² Western and Eastern Europe (UN ECE region). Tax in 6 EU countries (France, Germany, UK, Italy, Netherlands, Denmark) and Scandinavia (Norway, Finland, Sweden) only

³ including road traffic benefits (reduced congestion, noise, accident, and road damage costs)

⁴ SO_x

⁵ PM₁₀ / TSP

Sources: as shown.

Table 6.13 The Social Costs of Air Pollution (\$/tonne)

Country	SO ₂	NOx	CO	Particulates	VOC	Source
UK	367	124	15	21,333	n.a.	Pearce (1994)
UN ECE ¹	637	490	n.a.	21,333	n.a.	Pearce (1994)
Norway	500 - 7,600	1,600 - 31,400	1 - 13	2,100 - 27,700	n.a.	Alfsen <i>et al.</i> (1992)
US	4,800	2,000	n.a.	2,700	n.a.	Ottinger <i>et al.</i> (1990)
US	300 - 1,800	10 - 100	n.a.	400 - 10,900	360 - 2,400	Scheraga and Leary (1994)

¹ Damage done by a tonne of UK emissions to Western and Eastern Europe, incl. UK (UN ECE region).

Sources: as shown.

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