Global Climate Change: Economic and Policy Issues
Edited by Mohan Munasinghe

Intertemporal Equity, Discounting, and Economic Efficiency
Kenneth J. Arrow, William R. Cline, Karl-Göran Mäler, Mohan Munasinghe, and Joseph E. Stiglitz

Applicability of Techniques of Cost-Benefit Analysis to Climate Change
Mohan Munasinghe, Peter Meier, Michael Hoel, Sung Woong Hong, and Asbjorn Aaheim

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Global Climate Change

Economic and Policy Issues

Edited by Mohan Munasinghe

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AN INTRODUCTION 
TO CLIMATE CHANGE POLICY ISSUES 

This volume contains three papers dealing with key issues and options relating to the economic and policy aspects of global warming. The first two have their origins in Chapters 4 and 5, respectively, of Working Group III of the Intergovernmental Panel on Climate Change (IPCC). The final paper is the outcome of a research collaboration, initiated in 1991, between the Decision Science Center, Wharton School, University of Pennsylvania, and the World Bank.

Intertemporal Equity and Discounting

In the first chapter, Arrow, Cline, Mäler, Munasinghe, and Stiglitz indicate that climate policy, like many other policy issues, raises particular questions of equity among generations. Such questions occur because future generations are not able to influence directly the policies being chosen today that could affect their well-being, and because it might not be possible to compensate future generations for consequent reductions in their well-being.

Sustainable development provides one approach to intergenerational equity—it “meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987). 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. Nevertheless, sustainable development would require that uses of exhaustible natural resources and environmental degradation are appropriately offset—for example, by an increase in productive assets sufficient to enable future generations to obtain at least the same standard of living as those alive today. Sustainable development has economic, social, and environmental dimensions (Munasinghe 1993). There are different views in the literature on the extent to which different forms of capital (e.g., infrastructure, knowledge, cultural assets, and natural resources) are substitutes for each other. Some analysts stress that there are exhaustible resources which are unique and cannot be substituted for. Others believe that the current generations can compensate future generations for decreases in the quality or quantity of environmental resources by increases in other resources.

The authors explain how discounting is the principal analytical tool economists use to compare effects that occur at different points in time. The choice of discount rate is of crucial technical importance for analyses of climate change policy because the time horizon is extremely long, and mitigation costs tend to come much earlier than the benefits of avoided damages. The higher the discount rate, the less future benefits and the more current costs matter in the analysis.

Selection of a social discount rate (which is the discount rate appropriate for use by governments in the evaluation of public policy) is also a question of values, since it inherently relates the costs of present measures to possible damages suffered by future generations if no action is taken. How best to choose a discount rate is, and will likely remain, an unresolved question in economics. Partly as a consequence, different discount rates are used in different coun-

1. A related (somewhat stronger) concept is that each generation is entitled to inherit a planet and cultural resource base at least as good as that of previous generations.
tries. Analysts typically conduct sensitivity studies using various discount rates. It should also be recognized that the social discount rate presupposes that all effects are transformed to their equivalents in consumption. This makes it difficult to apply to those nonmarket impacts of climate change which for ethical reasons might not be, or for practical reasons cannot be, converted into consumption units.

Chapter 1 shows that the literature on the appropriate social discount rate for climate change analysis can be grouped into two broad categories. One approach discounts consumption by different generations using the "social rate of time preference," which is the sum of the rate of "pure time preference" (impatience) and the rate of increase of welfare derived from higher per capita incomes in the future. Depending upon the values taken for the different parameters, the discount rate tends to fall between 0.5 percent and 3.0 percent per year on a global basis using this approach. However, wide variations in regional discount rates exist, which are consistent with a particular global average.

The second approach to the discount rate is based on market returns to investment, which range between 3 percent and 6 percent in real terms for long-term, risk-free public investments. Conceptually, funds could be invested in projects that earn such returns, with the proceeds being used to increase the consumption for future generations.

The choice of the social discount rate for public investment projects is a matter of policy preference, but has a major impact on the economic evaluation of climate change actions. For example, in today's dollars, $1,000 of damage 100 years from now would be valued at $370 using a 1 percent discount rate (near the low end of the range for the first approach) but would be valued at $7.60 using a 5 percent discount rate (near the upper end of the range for the second approach). However, in cost-effectiveness analyses of policies over short time horizons, the impact of using different discount rates is much smaller. In all areas, analysts should specify the discount rate(s) they use to facilitate comparison and aggregation of results.

Applicability of Cost-Benefit Analysis

In Chapter 2, Munasinghe, Meier, Hoel, Hong, and Aaheim broadly interpret cost-benefit analysis as a family of techniques that may be used to evaluate various projects and public policy issues. An analysis of costs and benefits, even if they cannot all be measured in monetary units, offers a useful framework for organizing information about the consequences of alternative actions for addressing climate change. The family of techniques involved starts with traditional project-level cost-benefit analysis, and extends to cost-effectiveness analysis, multicriteria analysis, and decision analysis. Traditional cost-benefit analysis attempts to compare all costs and benefits expressed in terms of a common economic numeraire, usually expressed in monetary units. An analysis of costs and benefits, even if they cannot all be measured in economic units, offers a useful framework for organizing information about the consequences of alternative actions for addressing climate change. Cost-effectiveness analysis essentially seeks to find the lowest cost option to achieve a specified objective. Multicriteria analysis is designed to deal with problems where some benefits and/or costs are measured in nonmonetary units. Decision analysis focuses specifically on making decisions under uncertainty.

In principle, this group of techniques could contribute to improving public policy decisions concerning the desirable extent of actions to mitigate global climate change, the timing of such actions, and the methods
An Introduction to Climate Change Policy Issues

...to be employed. In this context, cost-benefit analysis provides a systematic framework by which to determine a rule or target for undertaking climate change mitigation actions. It seeks to identify the most efficient climate change strategy by balancing the marginal costs of mitigation and adaptation measures against marginal damages avoided by those measures. In Figure 2–10c of Chapter 2, the cross-hatched curves represent uncertain marginal costs estimates and $R_{opt}$ is an estimate of the optimal (efficient) level of emission reduction.  

A second type of approach is based on the concept of an affordable safe minimum standard, which would specify a maximum atmospheric concentration of greenhouse gases based on an assessment of the risks associated with different atmospheric concentrations and the costs of achieving those concentrations. As shown in Figure 2–10b of Chapter 2, judgment is exercised to determine the affordable safe minimum standard $R_{min}$, so that the cumulative area under the marginal mitigation cost curve is less than some predetermined value of maximum affordable costs. Although less rigorous than the previous approach, the iterative use of risk and affordability criteria enable the policymaker to determine a standard without reference to an explicit marginal damage cost curve. Multicriteria analysis could be used to help choose the affordable safe minimum standard.

Finally, a more arbitrary rule may be derived based on an absolute standard. Such an approach, as shown in Figure 2–10a in Chapter 2, might define a maximum atmospheric concentration of greenhouse gases that is considered to constitute “dangerous anthropogenic interference with the climate system” on the basis of the risks posed by climate change. The vertical line implies that the (notional) marginal damage costs are very high, and therefore the standard may be set largely independently of the economic and social costs of achieving the standard.

These rule-making procedures need not necessarily be used in a mutually exclusive fashion. Rather, policy judgments may be improved by combining these perspectives, and recognizing that over time, targets and standards may need to be adjusted in the light of better data and analyses. Whatever the method or rule used to determine the desirable standard, cost-effectiveness analysis would be helpful in identifying the least-cost method of achieving such a standard.

The authors indicate that in the practical application of cost-benefit analysis to the problem of climate change, there are important difficulties because of the global, regional, and intergenerational nature of the problem. The literature on the consequences of climate change is thin, and even physical damage estimates vary widely. The literature on actions to address climate change is also limited. Economic valuation of the consequences of climate change is a central feature of traditional cost-benefit analysis, but confidence in valuation estimates for important consequences (especially nonmarket consequences) is low. For some categories of ecological, cultural, and human health impacts, even well-accepted economic concepts of value are not available. Furthermore, the techniques of cost-benefit analysis would not be useful in analyzing questions involving equity—for example, in determining who should bear the costs.

Cost-effectiveness and multicriteria analyses can be used to compare and evaluate specific adaptation and mitigation measures.

---

2. Emission reduction is used as a rough proxy measure for the state of the global environment. A more rigorous analysis would need to examine actual greenhouse gas concentrations and/or consequent changes in global temperature (both the level and rate of change would be important to determine, for example, the impact on the survival probability of many species).
Financing Global Environmental Programs

In the final chapter, Fernando, Fitzgerald, Kleindorfer, and Munasinghe address several issues related to global cooperation and international resource transfer for reducing greenhouse gas emissions to mitigate global climate change, currently an area of significant policy interest. Global environmental projects are quite unique because their benefits are shared globally, whereas investments have to be undertaken by the countries in which the projects are located. An economic framework is built around a group of countries or country groups with heterogeneous preferences and incomes to evaluate opportunities for efficiency gains through international resource transfers and to assess alternative institutional mechanisms for effecting these transfers. To illustrate this framework, the authors identify its parameters for 1989 data, and use it to simulate the outcomes associated with various levels of international cooperation and resource transfers.

The analysis clearly demonstrates that because of differences in project marginal benefits and country preferences, cross-border investments (e.g., by Organisation for Economic Co-operation and Development (OECD) countries, in greenhouse gas abatement projects located in developing countries) can create significant win-win situations from the standpoint of all countries (i.e., those who fund and those who host investment), relative to more autarkic outcomes where all such investments are carried out by the individual countries concerned. Thus, rather than seeing a trade-off between equity and efficiency, as is sometimes presented in the economics literature, it is argued that, in the present context, these two welfare criteria are mutually reinforcing. The focus of transfers is clearly to promote efficiency through targeted project funding. But the process of identifying, implementing, and monitoring optimal project funding opportunities requires cooperation from the countries in which projects are located. Obtaining this cooperation, together with a commitment to greenhouse gas mitigation targets and funding procedures, will require a sense of perceived fairness or equity in the burdens and benefits associated with these targets and procedures. Absent this sense of equity, only a range of noncooperative outcomes becomes possible for the global coalition. To the extent that such noncooperative outcomes entail efficiency losses, maintaining a sense of perceived equity is efficiency enhancing.

The success of a global environmental investment program depends critically on the institutional mechanism that is employed for implementing it. The authors compare and contrast multilateral (e.g., through a Global Environment Facility—GEF) and bilateral (e.g., joint implementation) schemes. A critical feature that differentiates these schemes is the allocation of the surplus associated with individual investments between the investing countries (and by extension, the global community) and the host country. The GEF as it is currently constituted, pays out incremental costs to the host countries, thereby capturing the entire project surplus for the global community. This may dampen incentives for selection of projects and their speedy implementation, while also increasing the transactions costs to the global community. The chapter concludes by examining more decentralized and market-oriented approaches, both bilateral and multilateral, which through the allocation of part of the surplus to host countries, have the potential to resolve these problems and considerably speed up the implementation of global environmental projects.

Concluding Remarks

Industrial and developing countries differ in their capabilities and viewpoints
An Introduction to Climate Change Policy Issues

with regard to solving global environmental problems. The industrial countries have already attained most reasonable goals of development, and thus, they can better afford to commit resources to global environmental protection even at the expense of further material growth. By contrast, developing countries have limited ability to resolve even domestic environmental problems—they can be expected to participate in global environmental programs only to the extent that such participation is consistent with their national objectives, such as poverty alleviation and economic growth. Technology and capital transfers from the industrial countries are essential to enable the developing countries to contribute toward the protection of the "global commons" (Munasinghe and Munasinghe 1991).

Currently, discussions are under way within the Framework Convention on Climate Change (FCCC) to define effective criteria and mechanisms for both mobilizing and allocating funds to address global environmental issues. While a broad workable agreement will not be easy to reach, the analysis and resolution of global financing issues may be facilitated through a trade-off involving several criteria: affordability/additionality, fairness/equity, and economic efficiency.

First, developing countries cannot afford to finance even their present energy supply development. Therefore, to address global environmental concerns, they will need financial assistance on concessionary terms that is additional to existing conventional aid. The latter will have to be increased also, to assist developing countries in dealing with local environmental degradation.

Second, the disparity in energy use (and per capita income) between the industrial and developing countries raises issues in the context of current global environmental concerns, and the heavy burden placed on mankind's natural resource base by past economic growth. A good example of this is the accumulation of greenhouse gases, particularly CO₂, in the atmosphere due to the use of fossil fuels. The industrial countries accounted for over 80 percent of such cumulative worldwide emissions from 1950 to 1986—North America contributed over 40 billion tons of carbon, Western and Eastern Europe emitted 25 and 32 billion tons respectively, and the developing countries' share was about 24 billion tons. On a per capita basis, the contrasts are even more stark—North America emitted over 20 times more CO₂ than the average developing nation. Furthermore, the industrial countries as a whole were responsible for over eleven times as much total cumulative CO₂ emissions as the developing world.

Clearly, the development of the industrial countries has effectively exhausted a disproportionately large share of global resources—broadly defined to include both the resources that are consumed in productive activity (e.g., oil, gas, and minerals), as well as environmental assets that absorb the waste products of economic activity and those that provide irreplaceable life support functions (like the high-altitude ozone layer). Indeed some argue that this development path has significantly indebted the industrial countries to the rest of the global community (Brundtland Commission Report 1987). If the division of responsibility in the worldwide effort to resolve global environmental problems were to be based fairly on the past use of common resources, then the industrial countries would be required to assume a bigger role than the developing countries in protecting the "global commons." This approach would also help determine how the remaining finite global resources may be shared more equitably and used sustainably.

Finally, the economic efficiency criterion indicates that the "polluter pays" principle may be applied to manage energy demand and generate revenues, to the extent that global environmental costs of human
activity can be quantified. If total emission limits are established under a permit system, then trading in emission permits among nations and other market mechanisms can be harnessed to increase efficiency.

The principle of international assistance to developing countries for environmental protection efforts, specifically in terms of technology transfer and financial support, is already well established. One assistance mechanism that has been established is the Global Environment Facility, to finance investment, technical assistance, and institutional development activities in four areas: global climate change, ozone depletion, protection of biodiversity, and water resource degradation. Another is the Ozone Fund, which has been set up to help implement measures to reduce the emission of ozone-depleting substances like chlorofluorocarbons (CFCs) under the Montreal Protocol. Both funds are being managed under a collaborative arrangement between the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank. In particular, they provide concessionary funds to those activities that would yield cost-effective benefits to the global environment, but would not have been undertaken by individual countries without such financing, because the measurable benefits to a national economy are too low to trigger own investment.

To summarize, developing country participation in the protection of the "global commons" will critically depend on the financial assistance that they will receive from the international community. Without such assistance, one can only expect that, because of their difficult economic circumstances, the poorer countries' response to global environmental protection issues will be restricted to those measures that are consistent with their short-term development goals. It is, therefore, important that the industrial countries provide the financial resources that the poorer nations need today while developing the technological innovations to be used in the twenty-first century.

Bibliography


1. Intertemporal Equity and Discounting

Kenneth J. Arrow, William R. Cline, Karl-Göran Mäler,
Mohan Munasinghe, and Joseph E. Stiglitz

Introduction

This chapter considers methods for comparing costs and benefits that fall at different times, especially where trade-offs occur across generations. How we think of these trade-offs involves issues of intertemporal equity. This issue is a matter of ethics and morals because it involves reaching judgments 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, opportunities for productive investment, and trade-offs across generations.

Importance of the Discount Rate

The discount rate allows analysts to compare economic effects occurring at different points in time. Identifying the appropriate discount rate has been discussed in the context of general cost-benefit analysis for many years (Dasgupta et al. 1972; Harberger 1976; Little and Mirrlees 1974; Sen 1967; Stiglitz 1982). Social scientists have debated the precise rate to use for global climate analysis (Broome 1992; Cline 1992; Nordhaus 1993) analysts agree that the choice of a discount rate powerfully affects the analytical results.

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 order to yield the same future amount. Greenhouse gas (GHG) emission control may be viewed as an investment: money is spent today on emission controls to reduce the future 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 GHG emissions; the converse also holds, provided that the money is spent on emission control.

Because the benefits of greenhouse abatement accrue decades or even centuries in the future, use of a high discount rate results in a low present value for actions that slow climate change. For example, at a discount rate of 8 percent annually (as is commonly used in short-horizon project analysis), damages of $1 billion 50 years hence have a present value of only \[\frac{1 \times 10^9}{1.08^{50}} = 21.3\text{ million} \] the same damages 200 years hence have a present value of only $200. Conversely, if the real rate of return to investment is 8 percent, and if the returns are continuously reinvested, then a foregone investment of only $200 now will result in lost consumption of $1 billion in 200 years.

The question of the appropriate discount rate involves issues in normative as well as positive economics. Normative or ethical questions include: how (ethically) should impacts on future generations be valued? Positive questions include: to what extent will investments made to reduce GHG
emissions displace investments elsewhere? The debate is often confusing, in part because three separate issues are being addressed: how to discount the welfare or utility of future generations; how to discount future dollars; and how to discount future pollution. Further, the argument often combines questions of efficiency and questions of ethics; while economists can make no special claim to professional expertise in questions of ethics, they have developed rigorous methods for analyzing the implications of ethical judgments. (See Box 1–1.)

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

Areas of Agreement and Disagreement

Economists focus their attention on the trade-off between consumption today and consumption in the future—first, how to think about it, and second, what value to attach to it. Most economists subscribe to a general framework for thinking about these trade-offs that subsumes many subtopics to be discussed below, including treatment of risk, valuing of nonmarket goods, and treatment of intragenerational equity. Economists generally believe that the social rate of discount on goods (sometimes called the social rate of time preference or SRTP) can be expressed as:

\[
\text{SRTP} = \rho + \theta g, \quad (1.1)
\]

where \(\rho\) is the rate of "pure" time preference (the utility discount rate), \(\theta\) is the absolute value of the elasticity of marginal utility, and \(g\) is the growth rate of per capita consumption. This equation sets out explicitly the two reasons for discounting future consumption: either one cares less about tomorrow's consumer than today's, or about one's own consumption tomorrow than today (reflected in the first term, \(\rho\)); or else one believes tomorrow's consumer will be better off than today's (reflected in the second term, \(\theta g\)). For a discussion of the derivation of equation 1.1, see Annex 1–1.

Economists are in general agreement on the range of empirical estimates of returns to investment, and the average interest rate earned or paid by consumers. Most economists also believe that considerations of risk can be treated by converting outcomes into

Box 1–1: Is Discounting the Right Approach?

One prominent economist, Thomas Schelling, argues against the way discounting is generally applied to climate change projects. Schelling notes that discussions of discounting for climate change policy often confuse three ideas: 1. discounting for consumption enjoyed in the future (the pure rate of time preference for utility); 2. discounting for risk; and 3. discounting for consumption by others.

Schelling points out that one thinks differently about one's own consumption than about the consumption of others, and that essence of climate change policy 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, says Schelling, we should recognize that climate change mitigation is more like foreign aid than it is like the usual public investments we apply discounting to. Foreign aid budgets are low because the donors do not have strong feelings of concern for the beneficiaries. In the absence of evidence to the contrary, says Schelling, there is no reason to impute much stronger moral sentiments to those who will be paying for climate change mitigation.
“certainty equivalents” (Raiffa 1958). In addition, economists generally believe that future generations could be compensated for some loss of environmental amenities by offsetting accumulations of capital.

Economists disagree on several other issues that affect the choice of a discount rate, including key parameters such as the likely rate of future per capita economic growth, the proper approach to analyzing uncertainty in this estimate, and how to convert investment into consumption equivalents. These calculations require economic judgments about the degree of economic efficiency reflected in market outcomes, the extent of constraints on policy, and the proper approach to distributional concerns. Disagreements on these points drive the differences in conclusions about the discount rate.

The next section sets out the building blocks of the analytical approach, introducing the key technical terms. There follows a presentation of the two most prominent approaches to discounting for climate change programs, together with the reasons for the differences in the conclusions they reach.

### Building Blocks of the Analytical Approach

Normative analysis often begins with a social welfare function, an algebraic formulation that “adds up” the consumption of different individuals, yielding a measure of the well-being of society as a whole. The usual approach begins with conditions in the “first best” world: with complete markets and optimal redistribution policy, it can be shown that the discount rate will equal the marginal product of capital, which will equal the interest rate faced by both producers and consumers (Lind 1982).

In this case, an optimal path must be efficient in three senses (Lind 1982):

1. production: the marginal rate of transformation in production between one period and the next, and thus the marginal product of capital, equals the producer rate of interest for all goods: $MRT_j(t,t+1) = i$, i.e., the marginal rate of transformation for any good $j$ from period $t$ to period $t+1$ equals the producer rate of interest $i$.

1. Issues of equity can be treated analogously, through the use of “equity equivalents” (Atkinson 1970; Rothschild and Stiglitz 1973).

2. The alternative view, which could be called environment-specific egalitarianism, says that each good must be valued in isolation from all others. This view stresses the need for limits to the use of resources that will be needed, but cannot be created, by future generations (Pearce and Turner 1990). In the extreme, this belief, known as specific egalitarianism, argues (a) that environmental goods (and in some cases, each environmental good) must be treated separately from all other goods, and (b) that each generation should enjoy the same level of environmental benefits as previous generations.

   The mainstream view in economics holds that future generations can be compensated for decreases in environmental goods by offsetting accumulations of other goods (though increasing scarcity of some environmental goods will require increasing amounts of capital to offset the loss of an additional unit of the environmental good). Environmentalists may favor restricting the use of nonreproducible environmental resources in a way entirely consistent with the mainstream view, in that risk aversion in the matter of environmental quality will affect the rate at which society trades environmental goods for other goods. Only in the limiting case of infinite risk aversion will no tradeoffs be made. Thus adherents of environment-specific egalitarianism may back the same policies as risk-averse adherents of the mainstream view.

   Should decision makers accept the current generation’s valuation of the future benefits of environmental goods, as reflected in the market? Even those who believe the answer is “no” may accept trading off environmental for other goods, though those tradeoffs may not be well reflected in current market prices.

3. Using only lump-sum taxes, i.e., with no distortions.
consumption: the ratio the marginal utility of consumption in period \( t \) to the marginal utility of consumption in period \( t+1 \) equals 1 plus the consumer interest rate, or \( \frac{MUC_t}{MUC_t} = 1 + r; \) and

\[ \text{(3) overall: the consumer interest rate equals the producer interest rate for all goods, for all consumers, in all time periods: } r = i. \]

The literature then addresses departures from the “first-best” assumptions. Taxes drive a wedge between \( i \), what producers pay to borrow, and \( r \), what consumers receive on their savings. If money for public investment comes entirely from other investment, then the discount rate should be the producer interest rate \( i \). If the money comes entirely from consumption, then the discount rate should be the consumer interest rate \( r \). If the money comes partly from investment, and partly from consumption, then the appropriate discount rate will fall somewhere between \( r \) and \( i \); the exact answer requires an explicit analysis of how climate policy affects investment and consumption.

If no-cost intergenerational transfers are possible, then the efficiency requirement continues to hold, and the discount rate must equal the marginal product of capital (Stiglitz 1982). Even with a nonoptimal tax policy (i.e., with differing tax rates on different forms of income), but with no constraints on income transfers, maximizing a social welfare function (SWF) still requires the three efficiency conditions above, but the discount rate may not equal the marginal product of capital (Stiglitz 1982).\(^4\) In the general case in which these conditions do not hold, no single discount rate can be applied; rather, efficiency requires project-specific discount rates.

With suboptimal taxes, and constraints on intergenerational transfers, market rates are no longer a reliable indicator of the appropriate discount rate, which may be greater than or less than the before-tax return on investment (Stiglitz 1982). In the general case, no theoretical rule connects the discount rate to any observed market rate, although market rates still contain valuable information that should be used in arriving at a discount rate.

What is called below the prescriptive approach begins with a SWF constructed from ethical principles. It emphasizes departures from “first-best” conditions, especially nonoptimality of the tax system, and constraints on intergenerational transfers. What will be called the descriptive approach, on the other hand, begins with the SWF im-

\[ \text{plausibility of the assumptions. For instance, with } 100 \text{ percent profit taxes, no constraints on commodity taxation other than the ability to impose lump-sum taxes, then public projects should be evaluated at the producer rate of interest (Diamond and Mirrlees 1971). If there are profits and rents, and the government does not impose 100 percent profit and rent taxes, then the correct discount rate is not the producer interest rate, and is more likely to lie between that and the consumer interest rate (Stiglitz and Dasgupta 1971). If the government can impose optimal progressive taxes, and there are no constraints on taxation other than the ability to impose individual-specific lump-sum taxes, then there should be no capital income tax, and accordingly, the appropriate discount rate is either the consumer’s discount rate or the producer’s. If the government can impose an optimal linear income tax on the, to a first-order approximation, this result still holds under a broad range of assumptions (Stiglitz 1974). If, on the other hand, there are constraints on the ability to redistribute income across generations in a lump sum manner, taxation is distortionary, and the before-tax distribution of income can be affected by government policy (as seems realistic) then the discount rate may differ from either the consumer or producer rate (see Stiglitz 1985, 1988).} \]

\[ \text{4. More difficult questions arise when costless intergenerational transfers and other second-best considerations (such as lump-sum taxes) are employed. A few extreme cases yield unambiguous results, although interest in these cases is motivated by the simplicity of the results rather than by the} \]
plied by actual government and private decisions (the prescriptive approach, in contrast, implicitly assumes that government decisions do not reflect the true SWF). The descriptive approach says that decisions or public investments should be consistent with this SWF, and looks to actual behavior to determine a discount rate consistent with that SWF. While the descriptive approach assumes that governments are already undertaking transfers across generations that are optimal under the prevailing SWF, the prescriptive approach assumes that governments cannot or will not do so.

**Prescriptive Approach**

Those who hold the prescriptive view emphasize:

1. market imperfections and suboptimal tax (and sometimes expenditure) policy;

2. constraints on policy, especially the difficulty in making transfers to future generations;

3. distribution. They acknowledge that using a low discount rate means some sacrifice in efficiency; but they point to the suboptimal structure of current tax policy, and believe that, as with other programs with a goal of distributional equity (such as food subsidies), the gain in equity justifies some loss in efficiency; and

4. equalizing the marginal utility of consumption. They assert that public investment should move toward equalizing the marginal utility of society’s consumption at different times.

**Formulation of Prescriptive Approach**

The first term in equation 1.1 is the rate at which utility is discounted because it occurs later rather than sooner. Advocates of the prescriptionist view sometimes refer to this term as discounting for impatience or myopia.5 The second term 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 at rate $g$, then an extra unit of consumption in the future should be discounted by the term $\theta g$ to take account of the lower marginal to utility of consumption at higher consumption levels. Thus, even if present and future generations are given equal weight, so that pure time preference is zero ($p = 0$), future consumption would still be discounted if later generations are expected to be better off, in which case an extra unit of consumption would not be worth as much in the future as it is today. If the technological optimists are correct in their belief that technical change will continue at the pace of the last century, with productivity and living standards doubling about every thirty years, then additional benefits to future generations will count much less, implying a higher discount rate.6

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5. The earliest economics literature, in addressing these issues, argued that the appropriate value of $p$ was zero (Ramsey 1928). Ramsey based his argument on the ethical presumption that all individuals, including those living in different generations, should be valued the same. The argument since then has advanced only slightly. Some have argued that the discount rate should be adjusted for the probability of extinction (Yaari 1976). Plausible estimates of this effect would add very little to the discount rate. Others have pointed out that a positive discount rate is needed for acceptable optimization results: in the absence of a discount factor, the sum of future utilities may be infinite, so that the mathematics of maximizing a social welfare function is ill-defined. Because even a very small positive discount rate, however, would resolve the mathematical issue, this objection has little practical moment.

6. Not yet resolved is how to deal with uncertainty in forecasting $g$. The post-1973 slowing of productivity increases in many OECD countries suggests a reexamination of historical trends, and
The prescriptive approach arrives at the following conclusions:

1. The social rate of time preference should be employed, as it reflects society's views concerning trade-offs of consumption across generations.

Those who advocate the prescriptive case often assert that in the real world—that is, without the ability to make intergenerational transfers, and in the absence of optimal tax policy—the SRTP will in general fall below the producer rate of interest.

2. The cost of a greenhouse mitigation project must include the foregone benefits of other competing investments not undertaken. This means that costs should be adjusted for the shadow price of capital. If a mitigation project would displace private investment, and 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. Only after doing this will it be appropriate to use the social rate of time preference.

3. Uncertainty about 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.7

4. In evaluating competing projects, all spending, including investment, is to be converted into consumption equivalents first, then discounted at the social discount rate (Arrow and Kurz 1970; Lind 1982). Environmental impacts can be incorporated by converting them to consumption equivalents, and discounting at the social rate. 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. However, given appropriate estimates of relative prices, there is no reason to explicitly modify the discount rate.

The opportunity cost of capital (the market rate of return) usually exceeds the SRTP, suggesting the existence of better alternatives than those barely satisfying, say, a 2 percent rate of return criterion. Why then have the SRTP and market rates of interest not been brought into accord? Prescriptionists argue that other alternatives are not feasible—that society is not likely to be able to set aside investments over the next three centuries, earmarking the proceeds for the eventual compensation of those adversely affected by global warming (of course, faster economic growth would compensate at least some of those harmed by climate change). Accordingly, if the long-

7. The error of using a higher discount rate to reflect risk is particularly apparent in addressing issues of climate change. The uncertainty associated with the benefits of emission reduction would be less important with the use of a higher discount rate. This discussion applies only to the risk in return to investment (e.g. in mitigation), not to risks associated with changes in general standards of living.
term consumption rate of discount is 1 percent to 2 percent, say the prescriptionists, then a climate change investment returning 2 percent is better than no investment at all. To the argument that a discount rate of 2 percent 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 in one area on the basis of ethical considerations is no reason to insist that decisions in other areas be consistent with that initial decision.

Annex 1–2 (Technical Notes) discusses these issues in more detail.

Discount Rate Estimates—Prescriptive Approach

The prescriptive approach, beginning with a SWF derived from ethical principles, leads to low discount rates for changes in consumption of future generations. Assuming that the pure rate of time preference (ρ) is zero, then high rates of productivity increase (and thus high g), of the order of 1.5 percent, and high (absolute) values of the elasticity of marginal utility (θ), imply a social discount rate of about 3 percent. With low rates of productivity increase, of the order of .5 percent, and low (absolute) values of the elasticity of marginal utility, the social discount rate is of the order of .5 percent (Cline 1992), again assuming ρ=0.

It must be emphasized that these discount rates apply to consumption only, and that they can be applied only after the foregone benefits of other investments not made have been included in the costs of the program. If the foregone investments would have produced a high return, then calculated output and future consumption will suffer, making the mitigation program less attractive.9

In general, there is no reason that the discount rate should be constant over time even if ρ and θ are constant, since g need not be constant. In a gloomy scenario, in which future output and consumption decline, then g and thus the SRTP may be negative (Munasinghe 1993).

By the same token, developing countries, with higher rates of productivity increase, can justify higher rates of discount, at least until the gap between their standards of living and those of the more developed countries has been closed. With labor productivity increases and per capita income growth of the order experienced by the Asian miracle countries of 5 percent to 8 percent per year, and elasticities of marginal utility of 2, discount rates of the order of 10 percent to 16 percent could be justified. Similarly, low-income countries close to subsistence levels could have high elasticities of marginal utility (rapid drop-off of marginal utility from initially extremely

9. Some care must be taken in inferring the appropriate opportunity cost of capital from observed market rates of return. First, many standard measures reflect average rates of return, rather than the relevant marginal rates. Second, most investments carry some risk. The prescriptionist approach converts all returns to their certainty equivalent, including the foregone returns on displaced investments. Cline (1992) observes that investors purchase both safe government bonds yielding about 1.5 percent real, and stocks, yielding 5 percent to 7 percent real; he argues that this suggests a risk premium of 3.5 percent to 5.5 percent. Thus, if the average observed return to capital is 7 percent, and if the marginal return is less than the average (as one would expect), then the certainty equivalent opportunity cost would be less than 3.5 percent. On the other hand, it has also been argued that this calculation holds only if it is assumed that households allocate assets efficiently (an assumption that prescriptionists deny in other contexts); that bonds have risks quite different from either stocks or climate mitigation investments; and thus that this comparison is invalid (Nordhaus 1994).

8. Standard estimates put this elasticity between 1 and 2. Such estimates are based on an additive social welfare function using elasticities of marginal utility revealed by behavior toward risk. Though specialists debate the appropriateness of the assumptions, no generally accepted view supports a different value of θ.
high levels associated with privation), so that their SRTPs could be high even if they were experiencing slow growth over long periods. These distinctions have important implications for global warming policy, because they would tend to mean that the calculus of trading off present abatement costs against future benefits from avoidance of global warming damage could be less attractive for developing countries than for industrial countries. However, there are other elements in the calculus that could go the other way, such as the likelihood of higher relative future damage from global warming for the developing countries.

Specific applications in the still new economic literature on global warming have adopted different discount rates. To follow the approach suggested by Cline (1992), with a zero rate of pure time preference ($\rho$), and using the consumption growth rate of 1.6 percent per capita from the IPCC scenarios (IPCC 1992) multiplied by an elasticity of marginal utility ($\Theta$) of 1.5, gives an SRTP of 2.4 percent. If instead it is assumed that per capita growth is only 1 percent (perhaps because of slower growth after 100 years), or if $\Theta = 1$, then the SRTP becomes 1.5 percent. After taking account of the share of resources coming out of capital (20 percent economy-wide, versus 80 percent out of consumption) and taking into account the opportunity cost of displaced capital and depreciation, the effective discount rate becomes 2 percent to 3 percent.

Annex 1-1 gives details of the mathematics of the social rate of time preference. The SRTP approach values the total change in consumption at each date, not just the direct outputs of the project. Where mitigation projects displace other investment, future consumption must be reduced by the consumption that the displaced investment projects would have generated. (This requires an explicit analysis of the project’s effects on consumption and investment.) The SRTP is then applied to net consumption. Put another way, all effects are converted to their consumption equivalents, then discounted at the SRTP.

**Descriptive Approach**

The other widely-employed approach focuses on the (risk-adjusted) opportunity cost of capital. Most global warming optimization models (e.g. Nordhaus 1993a, b; Peck and Teisberg 1992; Manne et al. 1993) rely on the descriptive approach, which rests on three arguments:

1. mitigation expenditures displace other forms of investment; advocates of the descriptive approach advise decisionmakers to choose the action that satisfies the intertemporal efficiency conditions, and thus leads to the greatest total consumption (Nordhaus 1994).

2. if the return on mitigation investments lies below that of other investments, then other investments would make current and future generations better off. Transfers to future generations, if necessary, are to be considered separately; and

3. the appropriate social welfare function to use for intertemporal choices is revealed by society’s actual choices (hence the name, descriptive approach). Believing that no justification exists for choosing a SWF different from what decisionmakers actually use, advocates of the descriptive approach generally call for inferring the social discount rate from current rates of return and growth rates (Manne 1994).
Critics have questioned all three arguments.10

Formulation of Descriptive Approach

The descriptive approach to the discount rate looks at returns to investments in the real world, and with this information seeks intertemporal efficiency (see Table 1-1). It asks: could consumption be increased at one date without decreasing it at any other? The descriptive approach implies that a policy not intertemporally efficient should not be adopted.

A view current 50 years ago held that a project should be considered desirable if the winners could compensate the losers, whether or not this compensation actually occurred (Kaldor 1955; Scitovsky 1991). This “compensation principle,” no longer accepted, would support the view that the discount rate should be the producer cost of capital—what investments would have earned elsewhere in the economy. If a dollar invested in education, research and development (R&D), or new factories yields a return of 10 percent, and climate mitigation yields 5 percent, then converting climate mitigation investment to something more produc-

tive would yield higher total returns, implying that everyone could be made better off. The compensation principle would be satisfied. But compensation may not actually be paid, and future generations will probably not benefit from knowing that they might have been made better off. The modern version of the descriptive approach instead asks implicitly whether compensation is likely to occur, rather than whether it could possibly occur.11

As Manne (1994) demonstrates, a low SRTP implies a high rate of investment. But tax policy in most OECD countries significantly depresses the level of investment, which raises the return to investment at the margin, and is therefore inconsistent with a low SRTP. What conclusion to draw from this evidence depends on whether tax policy is viewed as a constraint (Stiglitz 1985) or as the result of optimizing a SWF. Most advocates of the descriptive approach hold the latter view. Descriptionists also emphasize that in the presence of multiple departures from perfect competition, the piece-

10. Critics have noted (a) that it is not in general the case that mitigation expenditures displace other forms of investment on a dollar-for-dollar basis; (b) the second argument can be read as stating the compensation principle (discussed in section 3.4.1), which holds that one need not ask if compensation has actually been paid, only whether it could be paid, so that questions of distribution and efficiency can be separated; (c) the third argument assumes the presence of lump-sum redistributive mechanisms, in the absence of which, the social marginal rate of substitution may not equal the opportunity cost of capital) and a degree of rationality in collective decisionmaking that may not be plausible. Society may not engage in optimal intergenerational redistribution; yet in evaluating a policy, it may still wish to consider explicitly intergenerational effects. Taken to an extreme, argument (c) would suggest that the social marginal utility of the rich must equal that of the poor, otherwise governments would have redistributed income already.

11. Economists consider two cases: (1) Pareto improvements—changes, including compensation actually paid, that make everyone better off; these are obviously desirable; and (2) changes that produce some winners and some losers. To address the second case, economists generally use a social welfare function, typically showing some preference for greater income equality (that is, increasing equality raises social welfare). A considerable literature, building on the work of Rothschild and Stiglitz (1971, 1972, 1973) has added precision to this idea. In choosing an SWF, economists also generally assume separability. That is, the SWF can be written $W = W(U_i, ...) = ...$. The ethical idea underlying this assumption is that society's willingness to substitute consumption between individuals $i$ and $j$ does not depend on the utility or income of individual $k$, a form of the assumption of the independence of irrelevant alternatives. Economists also generally assume consumer sovereignty. That is, each individual's utility (entering the SWF) is determined by that person's own judgments, not the judgments of society more generally. For qualifications, see the discussion of the concept of merit goods in Musgrave (1959) and Stiglitz (1982).
meal fix proposed in the prescriptive approach may make matters worse rather than better.

Some have claimed that on ethical grounds, it is difficult to support a rate of pure time preference much above zero. Others reply that the same argument cannot explain how individuals and nations actually behave. For example, development assistance budgets for the OECD countries average about one quarter of 1 percent of GDP—certainly inconsistent with the ethical arguments used to justify the assumption that \( \rho = 0 \).

Advocates of the descriptive approach have debated whether to use the producer interest rate \( i \) (the private rate of transformation between investment today and investment in the future); the consumer interest rate \( r \) (equal to the producer rate after taxes), or something in between. The choice depends in large part on the degree of distortion introduced in the tax system.

**Returns to Investment and Discount Rate Estimates—Descriptive Approach**

Nordhaus (1994), Lind (1994), Birdsall and Steer (1993), Lyon (1994), and Manne (1994), among others, have all stressed the importance of the opportunity cost of capital. A review of World Bank projects estimated a real rate of return of 16 percent at project completion; one study found returns of 26 percent for primary education in developing countries. Even in the OECD countries, equities have yielded over 5 percent for many decades, after corporate and other taxes, comparable to a pretax rate of at least 7 percent (see box).

Selecting a low discount rate of 2 percent implies there should be far more investment than actually occurs in any country now, and thus would require a big jump in savings rates to finance the increased investment (Manne 1994).\(^ {12} \) Manne 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 1 or 2 percent imply an unrealistically rapid near-term increase in the rate of investment. Manne thus concludes that a discount rate this low is grossly inconsistent with observed or plausibly anticipated behavior. On the other hand, some would interpret Manne's analysis as showing simply that the intertemporal equilibrium established by market economies differs markedly from that corresponding to the solution of an intertemporal maximization problem based on a social welfare function derived from ethical considerations.\(^ {13} \)

But even if savings could be increased enough to drive the discount rate to 1 or 2 percent, climate change investments would still have to compete with many other public and private investments offering higher returns. Birdsall and Steer of the World Bank (1993) explain the problem:

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12. That is, if the social welfare function implied a 2 percent discount rate, and the government employed policies to maximize social welfare, then the savings rate would be very high.

13. 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 1972). However, considerable evidence weighs against Barro's hypothesis. Manne's analysis does not take into account the possibility of a nontradable third factor ("entrepreneurship"), which could lead to low marginal returns on investment. Indeed, using neoclassical models, it is hard to reconcile observed differences in real rates of return between developing and developed countries, given the large differences in capital-labor ratios (Stiglitz 1988; Lucas 1988).
...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.¹⁴

These apparently small differences in rate of return result in large differences in long-run results. Over 100 years, an investment at 5 percent returns 18 times more than one at 2 percent. Thus, where some redistribution of future returns is possible, society would be foolish to forgo a 5 percent return for a 2 percent return.

¹⁴. It might be argued that resources could still be channeled to the best projects using a lower discount rate, by employing a shadow price of capital, reflecting the scarcity of capital. The issue of the intertemporal price and the current scarcity price of capital can, in principle, be separated.

Conclusion:
Reconciling the Two Approaches

Both the prescriptive and descriptive approaches include the opportunity cost of capital—directly in the case of the descriptive approach, indirectly in the case of the prescriptive approach, which takes account of the full impact on consumption, and thus of the cost of any displaced investment (see example of project evaluation in Table 1–2). The prescriptive approach looks at the risk-adjusted marginal return to capital, which may be considerably lower than observed average rates of return to capital. Refinements to the descriptive approach would take into account limitations on intergenerational transfers, including the absence of lump-sum redistributive taxes. In practice, both approaches may lead to similar results, and similar policy recommendations.
Annex 1–1
Methodological Notes on Discounting

**Intertemporal Maximization of Well-Being**

In an influential series of articles, Koopmans (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 percent 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 global warming, in part because of the much lower likely average return to capital over this time.

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:

\[
Z = \int_{t=0}^{\infty} W(c_t) e^{-\rho t} dt \tag{1A.1}
\]

where \( \rho > 0 \).

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

\[
i_t = i(c_t) = \rho + \theta(c_t) \frac{dc_t}{dt}/c_t \tag{1A.2}
\]

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:

\[
W(c) = c^{\theta} \tag{1A.3}
\]

As discussed in the text, the larger is the rate of pure time preference (\( \rho \)) the lower is the weight accorded to future generations’ well-being relative to that of the present generation. Mirrlee’s (1967) computations introduced this possibility (\( \rho > 0 \)) 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.

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

In (1A.3), \( W(c) \) is has no minimum value. If \( \rho = 0 \), this ensures that very low future consumption rates would significantly affect aggregate intertemporal welfare. On the other hand, if \( \rho \) were positive, low consumption rates by generations sufficiently far in the future would not penalized by (1A.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 $\rho$ 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 $\rho$ 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.

### 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:

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

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 investment.\(^ {15} \)

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

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\(^ {15} \) 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.
(discount factors) will differ from those associated with the consumption 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 $t^{th}$ generation's utility is represented by a utility function of the form:

$$U(c_t, c_{t+1})$$  \hspace{1cm} (1A.5)

where the first argument refers to consumption in the first period of the individual's life, the second to consumption in 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 $u'_2/u'_1$, while the latter corresponds to $u'^*_{t+1}/u'_1$.

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 percent 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).
### Table 1–1: Estimated Returns on Financial Assets and Direct Investment

<table>
<thead>
<tr>
<th>Asset</th>
<th>Period</th>
<th>Real return (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-income industrial countries:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>equities</td>
<td>1960-84 (a)</td>
<td>5.4</td>
</tr>
<tr>
<td>bonds</td>
<td>1960-84 (a)</td>
<td>1.6</td>
</tr>
<tr>
<td>nonresidential capital</td>
<td>1975-90 (b)</td>
<td>15.1</td>
</tr>
<tr>
<td>gvt. short-term bonds</td>
<td>1960-90 (c)</td>
<td>0.3</td>
</tr>
<tr>
<td>U.S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>equities</td>
<td>1925-92 (a)</td>
<td>6.5</td>
</tr>
<tr>
<td>all private capital, pretax</td>
<td>1963-85 (d)</td>
<td>5.7</td>
</tr>
<tr>
<td>corporate capital, post-tax</td>
<td>1963-85 (e)</td>
<td>5.7</td>
</tr>
<tr>
<td>real estate</td>
<td>1960-84 (a)</td>
<td>5.5</td>
</tr>
<tr>
<td>farmland</td>
<td>1947-84 (a)</td>
<td>5.5</td>
</tr>
<tr>
<td>Treasury bills</td>
<td>1926-86 (c)</td>
<td>0.3</td>
</tr>
<tr>
<td>Developing countries:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>primary education</td>
<td>various (f)</td>
<td>26</td>
</tr>
<tr>
<td>higher education</td>
<td>various (f)</td>
<td>13</td>
</tr>
</tbody>
</table>

*Sources:* (a) Ibbotson and Brinson 1987, updated by Nordhaus 1994; (b) UNDP 1992, table 4., results for G-7 countries; (c) Cline 1992; (d) Stockfisch 1982, 1989; (e) Brainard, Shapiro, and Shoven 1991; (f) Psacharopoulos 1985.
Table 1–2: 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:

<table>
<thead>
<tr>
<th>Option</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>0...</td>
</tr>
<tr>
<td>b.</td>
<td>0...</td>
</tr>
<tr>
<td>c.</td>
<td>-1...</td>
</tr>
<tr>
<td>d.</td>
<td>-1...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Option</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>0...</td>
</tr>
<tr>
<td>b.</td>
<td>0...</td>
</tr>
<tr>
<td>c.</td>
<td>-1...</td>
</tr>
<tr>
<td>d.</td>
<td>-1...</td>
</tr>
</tbody>
</table>

At discount rates below 10 percent, 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 percent 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.
Annex 1–2
Technical Notes on Discounting

The Social Welfare Function and Interpersonal Comparisons of Utility

Economists have long debated the equity of discounting distant future benefits (Ramsey 1928; Mishan 1975; Rawls 1971; Sen 1982). The usual 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 generations) only if it improves the position of the poorest. 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, as 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 as 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 (1971)
argued that income distribution is a public good, but that its value could be captured in individuals’ valuations. Although this probably 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.” It should be noted that this recommendation leads to paradoxes and inconsistencies.

**Relation to 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, 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. Prescriptionists note that the intertemporal distribution of welfare that emerges from the market will not, in general, maximize any particular social welfare function. 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.

Prescriptionists emphasize that 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 in general equal the SRTP. In standard life cycle models, with no technological progress and an economy in steady state, there would be no discounting for society’s purposes: each generation is identical, and 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 1965). In such models the market rate of interest would thus always overestimate the SRTP. Under some special conditions, with governments intervening with non-distortionary taxation to optimally redistribute income across generations, then observed market rates of interest will accord with the SRTP. But these are highly specialized conditions (see Stiglitz 1985; Pestieau 1972). The market rate of interest remains relevant because it reflects the opportunity cost of capital; the changes in consumption generated by any change in policy will be strongly affected by the opportunity cost of capital.

The prescriptionist view implies not only that transfers to future generations are constrained, but that climate change policies are the only way to make these transfers (Manne 1994). The descriptionist view, on the other hand, holds that we should choose the path
that maximizes consumption, making transfers among generations separately out of the larger present value of consumption. The alternative—overriding market prices on ethical grounds—opens the door to irreconcilable inconsistencies. If ethical arguments—rather than the revealed preferences of citizens—form the rationale for a low discount rate, cannot ethical arguments be applied to other questions? If it is argued, on ethical grounds, that it is unethical to pay rents (royalties) to oil companies, does that mean that cost-benefit calculations should use $2 for the price of oil? (Nordhaus 1994).

**Treatment of Future Generations: Sustainable Development**

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 economics. Perhaps best known among recent formulations, the report of the Commission on Environment and Development (World Commission on Environment and Development 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). Similarly, Brown-Weiss (1989, p. 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 an increase in the stock of capital (physical or human) can compensate for a decline in the stock of a natural resource. 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.

Economics has long recognized the concept of sustainability. Hicks (1946) used the idea in defining net national income. Neoclassical growth theory (Phelps 1961; Meade 1966; Robinson 1962) 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 1993). The recent economic debate on sustainable development has focused on two issues: (1) intertemporal equity and (2) capital accumulation and substitutability. The extent to which natural and cultural resources are substitutable is critical to this analysis and is contentious. Many economists (for example, Pearce and Turner 1990), stress the need for sustainability limits on the use of resources that future generations will need, but cannot create.

**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 global warming 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 nonlinearities 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 2xCO₂, 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 focus exclusively on the welfare of the less developed countries in the first place (note that in Rawls’ formulation, θ = ∞). 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.

Even the utilitarian approach (θ < ∞) 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 1.1) 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 GHG 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.

**Adjustments to the Discount Rate**

To review equation 1.1,

\[ SRTP = \rho + \theta g \]

This assumes a simple utility function, which is both separable in its arguments and stationary (in the time series sense).

**Impatience**

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.

The second term on the right side of equation 1.1 raises two questions. 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 \( \theta \), 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.

While it is also the case that no consensus has emerged on the answer to the second question, there is a generally accepted method 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 (\( \theta \) 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, the logarithmic, implies \( \theta = 1 \), meaning that if income rises by 1 percent the marginal utility of consumption falls by 1 percent. 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 (\( \rho \)) 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 the welfare of future generations, the higher the value of \( \theta \). 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 (as long as the two relative consumption levels did not reverse). Even \( \theta = 1 \) gives some emphasis to equity, 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).  

**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 $og$ 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 consumption, 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 global warming.

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. Further,

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16. With a nonutilitarian 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.

17. 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).
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 1973), though the likely effect on the appropriate rate of discount has yet to be thoroughly studied.

**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 empathic 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 global warming's effects on future generations).

**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 1 in 10,000). 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 1 in 10,000. The three-century horizon appropriate for global warming 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 1/2,500. The discount rate required for this shrinkage is vanishingly small (= 0.133x10^-4% 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
1. Intertemporal Equity and Discounting

failure of policy (breakdown into nuclear war). In any event this motive for extinction-based discounting would seem even less appropriate for the future.

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 (1.1). 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 (θ) 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 (Weitzsacker 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 (1A.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.

Another 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 developing countries. 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).

### 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.

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 can range from 2 to over 10 units of consumption equivalent per unit of capital (Lyon 1995).

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; Stiglitz 1988).

**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...
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(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 is equivalent to using a low (or even negative) discount rate for environmental amenities (see Annex 1–1), 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 1.1, as 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 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 global warming damage and optimal abatement, as 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.

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1. Intertemporal Equity and Discounting


2. Applicability of Techniques of Cost-Benefit Analysis to Climate Change

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In public policymaking, a comparison between the perceived costs and the perceived benefits of an action is routinely made by decisionmakers. 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 trade-offs. The basic principles are well understood and straightforward: for an action to be justified, the costs of the action should be less than the benefits derived therefrom. If there are several alternatives, then one ought to pick that option whose benefits most exceed the costs. The objective of this chapter is to examine how and under what circumstances CBA can make a contribution to the resolution of the central questions now facing decisionmakers 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 problem.

The section, Cost-Benefit Analysis, 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 the section, Unique Features of Climate Change, we examine the unique features of global warming and climate change as they pertain to decisionmaking. The section, Cost-Benefit Analysis in the Context of Climate Change, presents a discussion of the application of CBA to the climate change problem.

1. 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 U.S. 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 noneconomic grounds, and CBA could be used in a secondary role (see e.g. Turner 1991).

2. This rule needs some modification in the presence of capital constraints, which may limit selection of the “best” single project.

3. However, as we shall see later, extensions of CBA can help in identifying the trade-offs between economic efficiency and equity.
problem in light of these unique features. In the section, Issues, we discuss the key issues: risk uncertainty, irreversibility, valuation, discounting, equity, and multiple criteria.

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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 2–1) is too narrow to be relevant for evaluating climate change issues. However, modern 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, such as stabilization of the emission of certain GHGs by a given year. However, it might be more relevant to express the targets in terms of concentrations of atmospheric GHGs 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 2010 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.

Another 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 GHGs, 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 modern CBA is multicriteria analysis (MCA), a body of techniques developed to deal with the difficulties of economically valuing certain types of impacts (see Box 2–1). Indeed, even if one attempted to place economic value on certain impacts—such as human life—not
2. Applicability of Techniques of Cost–Benefit Analysis to Climate Change

Box 2-1: Techniques of Modern 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 the section entitled Issues.

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 dealing with irreversibility, one of the more important characteristics of the climate change problem.

everyone agrees that it is appropriate. Moreover, cost-benefit analysis presupposes

that costs and benefits are those that ultimately affect human welfare.

6. 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 genetic potential

5. The ethical and epistemological aspects of the climate change problem are not addressed here. For further discussion, see e.g. Brown (1992).
Such views give further support for MCA-based approaches to decisionmaking. 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, 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, 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 noneconomic efficiency criteria, as suggested in the figure. However, even such a noncardinal 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 noncompensable costs and benefits.

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 reductions. 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 percent reduction can be done cheaply, but the next 10 percent will cost substantially. In the section, Issues, we address the different types of value—use, option, existence—in more detail.

7. But see below for a discussion of the difficulties of making cross-country comparisons of costs.

8. There may also be some outcomes that are inefficient, i.e., those that lie inside the frontier of efficient points shown in Figure 2–1. Such an inefficient point is represented by option 6. This is discussed further in the presentation of multicriteria analysis, below.

9. 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.
considerably more, and so on. Thus the abatement cost curve is upward sloping (with increasing slope) as shown in Figure 2–2. Similarly, the marginal benefit (or avoided cost of GHG damages) falls as emission levels are reduced. The consequences of the foregoing is that the total cost (TC) is at its minimum at the point where the slope of the abatement cost curve equals the negative slope of the damage cost curve (or avoided costs).

The foregoing analysis ignores many complications. For example, the emission of a unit of CO₂ may give rise to a varying stream of environmental costs which must be discounted to yield a present value aggregate. The environmental damage function may be discontinuous and nonconvex. Abatement costs may change over time, depending on when the technologies are applied—because of technological progress. Similarly, abatement costs may exhibit economies of scale (e.g. mass production of solar photovoltaic cells), resulting in a marginal cost curve that actually declines beyond a certain point. Finally, the abatement costs are net costs, to the extent that certain technologies (e.g. renewables) may produce other (nonclimate related) benefits and costs—the so-called joint products complication (discussed below).

Unique Features of Climate Change

There are several important characteristics that define the conventional context in which CBA is applied. First is that costs and benefits arise within a time span typically no more than 15–25 years, corresponding roughly to the physical life of most projects over which benefits are derived. Second is that the elements of uncertainty are relatively tractable, and can often be characterized by probability distributions.

Most of these characteristics are very different in the context of climate change. The relevant time spans extend to a century or more. The uncertainties are extremely large, and few elements of uncertainty are amenable to characterization as probability distributions (see Figure 2–3). Moreover, the cascaded uncertainty implied in each link of the chain of causality greatly amplifies the total uncertainty in the final outcome, namely the extent of damage caused by climate change.

Figure 2–3 shows the chain of causality. It begins with emissions of GHGs. While the most important of these is CO₂ it should be noted that there are many other gases that contribute to the climate change phenomenon, including methane, and CFCs. While estimates of CO₂ emissions from fossil fuel combustion are fairly straight forward, emissions from other sources are subject to much higher uncertainty. Moreover, the separation of anthropogenic and natural causes of climate change is much more difficult than in the case of other important regional/global pollution issues (such as CFCs or nuclear wastes). Indeed, the calcu-
lus of CBA may be significantly affected by natural events such as major volcanic eruptions.

The first link (1) is between emissions and the resultant ambient concentration of CO$_2$ in the atmosphere. Unlike other pollutants that are subject to complex chemical transformations in the atmosphere,$^{12}$ the calculation of the ambient concentration increase that follows from a given increment of emissions of CO$_2$ is relatively simple. However, because of the role of natural sources and sinks (particularly the ocean), even this calculation is subject to a considerable degree of complexity and uncertainty.$^{13}$

The next link (2), between atmospheric concentration and temperature, is subject to much greater scientific uncertainty. The greenhouse effect itself, i.e. the trapping of incoming solar radiation, is subject to all kinds of additional factors that are highly complex. For example, if temperatures rise, and cloud cover increases, feedback effects involving increased reflection of incoming radiation will complicate the calculation of equilibrium temperatures.

The next link (3) involves many different components, all of which are to some degree difficult to calculate. For example, calculating the rise in sea level associated with increases in mean sea temperature proves to be far from simple in some cases (as noted in IPCC WGI in the case of the West Antarctic ice sheet). There are also large time lags associated with sea level rise, which is likely to continue for several centuries after the concentration of GHGs has been stabilized.

Even more complicated are estimates of how precipitation patterns might change, especially the spatial and temporal distribution of rainfall. Perhaps of even greater concern in the developing countries will be the changes in the patterns of extreme weather events, to which they are particularly vulnerable.

If these physical effects are understood in general terms, quantifying the impacts on the flora, fauna, and human beings is much more difficult (link 4). Suppose it were possible to predict the change in precipitation and temperature regime for some given region. What can be said about the shifts in vegetation patterns? While general poleward shifts of vegetation and agricultural production zones can be predicted in general terms, quantifying the effect is quite difficult. What is the impact on biodiversity? On wetlands? On the water table? On human communities? Clearly these are very difficult assessments to make.

Finally, in order to estimate the damage costs, one needs to be able to value these effects (link 5). Some valuation tasks will be relatively straightforward: for example, the cost of engineering structures to protect against sea level rise are relatively easy to establish, given the existing experience in this field (in such countries as the Netherlands). Other calculations will be more complex, but at least tractable: as for example, the calculation of increased cooling and decreased heating costs on the energy system, or the impact of increased irrigation pumping requirements associated with drier climates in some regions upon electricity demand. But a very large number of potentially important impacts will be very difficult to value—such as the impacts on forests, wetlands, and biodiversity, especially if the physical, biological and social effects have not been accurately quantified.

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12. The acidity of precipitation is influenced by complex interactions between sulfur oxides, related oxidation products, and NO$_x$.

13. For example, the presence of CFCs could affect climate change not only directly through its greenhouse warming potential, but also indirectly by its impact on biota like nannoplankton—which in turn influence oceanic CO$_2$ uptake. Similarly, the degree of reliance on fossil fuels would affect CO$_2$ directly, and CO$_2$ absorption indirectly—via the effects of acid rain on forests and biomass.
Special Features

Beyond the degree of uncertainty, what makes the analysis of the climate change problem so different from other environmental analysis problems? The main reasons can be summarized as follows.

GHGs Are Stock, Not Flow Pollutants

Many pollution phenomena are relatively short-lived, such that the damages are closely related to the current rate of emissions. This is because the rate at which most pollutants are removed from the atmosphere is relatively rapid (say in the case of particulates by dry or wet deposition). Reducing emissions at major sources will likely have a relatively immediate impact. In the case of GHGs, however, the damages occur as a result of the total atmospheric concentrations at any one time, in other words, are related to the stock of the pollutant, not to the current rate of emissions.¹⁴

Therefore, in the context of the climate problem, the global climate is a lagged function of the various GHGs. At any point of time, these atmospheric concentrations (which are stock concepts) depend on the whole time path of emission of the GHGs up till the point of time under consideration. Similarly, an increase in current emissions of a GHG at any point of time will affect the atmospheric concentrations of this gas, and thus the climate, in all future periods.

To calculate the marginal environmental cost of increased current emissions of a GHG, one must first calculate the physical impact of such an emission increase on the future development of the atmospheric concentration of the gas. This will depend on physical characteristic of the gas, which affect how rapidly an increased atmospheric concentration depreciates. There are large differences between different GHGs, with atmospheric lifetimes varying from some 15 years for methane¹⁵ to more than 100 years for \( \text{CO}_2, \text{N}_2\text{O} \) and some CFCs.

Once the impact of current emissions of a GHG on future atmospheric concentrations has been calculated, one can in principle calculate the effect of the increase in current emissions on the future climate development. If one has specified a function which measures the monetary cost of climate change, one may thus calculate the incremental costs, and thus obtain a present value measure of the marginal cost of increased current emissions of a GHG.

It is clear from the description above that the marginal monetary cost of GHG emissions is a complex concept. Several assumptions of an economic nature must be made, such as the appropriate discount rate and the monetary costs of climate change for the whole future. In particular, the relative importance of different GHGs is much more complex than some simple physical conversion into a common index. In the context of the climate problem, a reasonable definition of the importance of a GHG relative to, say, \( \text{CO}_2 \), is the marginal environmental cost of current emissions of this gas relative to the corresponding marginal cost of \( \text{CO}_2 \). It follows from the discussion above that the relative importance of GHGs depends on a number of economic assumptions which must be made.¹⁶

Inertia and Irreversibility

Since the emissions of GHGs in any one year represent a relatively small fraction of the total global stock, the system has great

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¹⁴. There are of course some exceptions, notably for radioactive wastes, which also have an extremely long life; thus the total environmental risk, and the scale of the disposal problem at any one time, is not so much dependent on current rates of production of nuclear wastes, as on the total stock.

¹⁵. The IPCC Special report 1994, estimates the lifetime of methane at 14.5±2.5 years.

¹⁶. See e.g. Hoel and Isaksen (1993, 1994) for a further discussion and numerical calculations.
inertia. This means that even if all emissions went to zero, it would be decades, if not centuries, before the stock of GHGs became reduced significantly. Therefore, in effect, decisions about emissions reduction become effectively irreversible, at least over the 100–200 year time span of interest. In other words, failure to reduce emissions in the short to medium term may be irreversible in the sense that once the effects of climate change become apparent, it will then be too late to do anything about it.

**Global Characteristics**

Most environmental pollution problems are local or regional in scale. The benefits of emissions reductions generally accrue to the same geographic areas as would otherwise bear the costs. The damage associated with GHGs, however, are dependent upon the total global GHG concentration, largely independent of the regional meteorological patterns that usually define the geographic scope of other transnational environmental problems such as acid rain. Therefore the distribution of benefits of emissions reduction is global, not local. Per contra, even a country that emits no GHGs would incur the damages of emissions by other countries.

**Geographical Distribution of Impacts**

Poorer nations are likely to be the most vulnerable to the impacts of climate change, since they lack the resources to protect themselves against sea level rise, extreme weather events, or desertification. For example, the impacts of acid rain tend to be concentrated in richer countries, from emissions in poorer countries or regions (richer West Germany from Eastern Europe). These richer areas therefore have powerful incentives to promote emissions reductions programs in the source areas, including the provision of financial assistance. By contrast, in the case of GHG emissions reductions, countries such as the United States (where there is the perception that the direct impacts of climate change on the United States itself are relatively small), may have less obvious economic motivation to reduce emissions.

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17. There are exceptions here as well, most notably the phenomenon of acid rain, which is largely a long-range phenomenon often involving emissions in one country, and acid rain damage in another. However, to the extent that lake acidification completely destroys aquatic ecosystems, one could argue that at least some of the impacts are irreversible, although even here the impacts are generally of a fairly local nature. Long time periods may also elapse between the onset of acid rainfall and actual visible damage.

18. For new data on emissions and acid deposition rates in Asia, see Interim Report, International Collaborative Project on Acid Rain and Emissions Reduction in Asia, World Bank, Asia Technical Department, September 1993.

19. To be sure, there are exceptions: for example, to some extent, even the richer countries of Europe among themselves are affected by mutual pollution problems (e.g., acid rain in Scandinavia from the United Kingdom, or the severe water pollution problems in the Rhine Basin involving Switzerland, 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 exist for addressing their problems (e.g., the EU in Europe) than are available for resolving environmental disputes between rich and poor.


21. However, the indirect impacts, for example large scale immigration from Mexico that might follow from agricultural devastation in that country, may ultimately prove to be much more serious for the United States than the direct consequences of sea level rise or higher energy bills for air conditioning: but 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.
solidarity and equity alone will unlikely be sufficient.

Absence of Actual Impact Data

Unlike almost all other environmental externalities, in the case of climate change it might be argued that there are few directly relevant actual data, and that predictions of physical impacts are based entirely upon the predictions, judgments, and models of scientists. Only once (or if) climate change does in fact occur, will the impacts be known. The evidence of cause-and-effect will be difficult to substantiate, because of the likelihood that, at least initially, changes will be incremental. It should be noted, however, that there does exist a significant body of verifiable scientific theory that underlies the estimates and models of scientists.

Nonlinearity

Global climate change is determined by complicated interactions involving a chain of nonlinear linkages (i.e., GHG emissions, atmospheric concentration, temperature change, physical impact). Therefore, climate change phenomena and risks are likely to be much more nonlinear than the relationship between conventional emissions and more local pollution.

Very Long Time Frame

The very long time frames involved in climate change make some of the normally exogenous variables endogenous. For example, the economic impact of sea-level rise is dependent upon the size of the population living in low-lying coastal areas, which may decrease once a sea level rise becomes evident. The costs of such adaptation mechanisms may be especially difficult to estimate.

Cost-Benefit Analysis in the Context of Climate Change

In light of these unique characteristics of the climate change problem, what can we say about the suitability of CBA? How and under what circumstances can CBA make a contribution to the central questions now facing decisionmakers: (1) By how much should emissions be reduced? (2) When should emissions be reduced? And (3) how should emissions be reduced?

The fundamental problem in applying CBA to the climate change problem follows 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 for GHG emission reductions have been derived for many industrial countries, but for only few developing countries. In Figure 2-4 we show such a curve for Thailand. This curve is derived by a rank ordering of the individual measures, by cost per ton of CO$_2$ saved (the height of each block), with the width of each block representing the tons of CO$_2$ so saved. The shape of the MAC curve, when smoothed, is indeed of

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22. In some cases laboratory experiments—such as growing plants in CO$_2$-enriched atmospheres—do of course provide some actual data for predictions.

23. 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).
the type indicated in Figure 2–2, a result confirmed by many other examples. 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. Such marginal cost curves depend upon discount rate and price.

What is interesting in these (and other studies) is the significance of "below the line" options (i.e. MAC is negative but still upward sloping). These are measures that appear to 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. 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). 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. If the GEF is to fund the "incremental costs" of GHG reduction measures, this presupposes that a baseline

24. See e.g. the review of eleven studies by London Economics (1992).


26. 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, D.C., 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 in Figure 2–5. 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.

27. 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 decisionmakers—there may be other, nonmonetary 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.

28. 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, D.C., 1993.
can be unambiguously defined, against which such incremental costs are to be measured. But under such a definition, should demand side management programs which have negative incremental costs—such as energy efficient lighting—be funded by GEF?  

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 2–5, 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. In this situation, an arbitrary level of emissions reduction at P, has a very high probability of at least meeting the criterion that MB>MC. By contrast, C may represent a risk averse, “precautionary” level of abatement, in which the expected values of MC may be greater than the expected value of MB (see the section Issues and Figures 2–10a – 2–10c for further details).

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 of some presumed level of GHGs in the atmosphere. Table 2–1 shows some estimates of the GDP impacts of climate change (whose avoidance represents the benefits of abatement).  

A number of estimates for the industrial countries (especially the well-known work of Nordhaus for the United States) suggest that the economic impact of climate change on the industrial 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 constraining.  

29. 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, U.K., 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, D.C., 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 nonoptimal.

30. 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)

31. It is interesting to note that while the totals agree rather well, the range in each component is quite large. This highlights the considerable uncertainty involved in making damage estimates.
small indeed. 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 settlements.

Unfortunately, to date, most of the discussions of impacts of climate change on the developing countries have been qualitative in nature, and there is an urgent need for more quantitative estimates for developing countries. According to a recent GEF survey of country studies, 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 United States.

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. 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 2–6 summarizes some of the estimates that have been made for GDP impacts.

32. This is likely to be true even though higher CO₂ concentration itself may promote plant growth.

33. 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).

34. See e.g. the discussions of P. Gleich, Climate Change and International Policies: Problems Facing Developing Countries, Ambio 18, 6, pp. 333–39, 1989; or R. K. Pachauri, Global Warming: Impacts and Implications for South Asia, Tata Energy Research Institute, New Delhi, 1991).


36. 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 Environments 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 county specific estimate of costs associated with specific levels of GHG accumulation in the atmosphere. ADB is currently sponsoring a multicountry project in Asia that is attempting to establish costs of potential effects.

37. There are several related issues. For example, should one use nominal exchange rates, trade-weighted rates, or purchasing power parity rates in making cross-country comparisons of costs or impacts?
2. Applicability of Techniques of Cost–Benefit Analysis to Climate Change

Thus it is well recognized that GDP is an imperfect proxy for social welfare. One recent Norwegian study (Alfsen, Brendemoen, and Glomsrud 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. 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 2-2).

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. Some of these problems are evident from the numerical estimates. In Figure 2-6 we display the results of recent studies of the impact of emissions reduction strategies on loss of GDP. As is evident, these impact estimates show considerable variation: even so, none of these estimates reflect "green accounting," or any margin for no-regrets options, and only one takes into account joint products. Most of these studies are national studies. Many researchers argue that unilateral action by the United States or by OECD countries are likely to be less effective than global action, and that unilateral actions are likely to exaggerate the impact on GDP. However, these studies also neglect the benefits of the development

38. 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.

39. The question of "green accounting" is one of valuing and aggregating marketable and nonmarketable goods (see, e.g., United Nations 1993 or Munasinghe et al. 1995). The many different proposals for "green accounting" reflect the difficulties involved. Rather than speculate about valuation, or poorly founded proxies for nonmarketable goods, MCA provides an alternative approach.

40. These results are for studies that estimate both emissions reductions and GDP impacts relative to some baseline, i.e., relative to the trajectory of emissions in the absence of the policies followed. For many countries, particularly the developing nations, even significant reductions from such baselines may still imply increases in the absolute quantity of GHGs emitted. Other studies report results in terms of GHG emissions in some future target year, relative to emissions in some prior year (e.g. 2010 emissions 10% less than 1990 emissions).


42. For further discussion see UNEP, op. cit., p. 72. Studies that have examined the question of unilateral v. multilateral approaches include Proost and van Regemorter (1990) for Belgium, and Edmonds and Rutherford (1992).
of advanced technologies in the market economies, which could then be more quickly adapted in the developing world.

Traditional CBA basically relies on a partial equilibrium framework which takes a large number of parameters, including prices, as given. For questions relating to climate change (whose consequences may have major effects on prices), the more far-reaching and inclusive general equilibrium approach is appropriate. For this reason, computable general equilibrium models are widely used in climate change studies.

**The Joint Products Problem**

A related question concerns the joint benefits and costs of emissions reduction. Options that reduce GHG emissions may also provide significant changes in other pollutants whose impacts are of a quite different scale. For example, the substitution of renewable energy technologies for coal will reduce not just CO\(_2\) emissions—a global benefit—but also SO\(_2\) and particulate emissions that bring a reduction in local environmental damages. On the other hand, the increased use of renewable energy technologies (such as hydroelectric generation), which also reduce CO\(_2\) emissions, may also impose new and different local environmental costs (such as loss of biodiversity associated with reservoir inundation).\(^4\)

Estimates of the importance of joint benefits and costs vary widely (in part because valuing the costs and benefits of other environmental impacts may be subject to similar difficulties of valuation and scientific uncertainty as for GHG emissions), but most lie in the range of $1 to $10 of additional benefits for every dollar of benefit from GHG emission reduction.\(^4\) A recent Norwegian study (Alfsen, Brendemoen, and Glomsrod 1992) indicated that when the joint products of carbon reduction were taken into account (reduction in environmental damages to forests and lakes, health damages, reduced traffic congestion, road damage, etc.), then such benefits go a long way toward compensating the economic loss measured as reduction in GDP.\(^4\)

Adding the benefits of reductions in joint pollutants to the MB measure is one possibility. The other is to subtract these benefits from the MC measure. Since most of such benefits go to the country that bears the costs of abating the CO\(_2\) emissions, while the benefits of less CO\(_2\) emissions go to all countries, it follows that the preferred approach is to adjust the marginal cost curves.

**The Aggregation Problem**

We now turn to the matter of implementing policy. Consider first Figure 2–7, which depicts the situation faced by some country. Its marginal cost curve is upward sloping, in the manner discussed above; it begins with negative values (the “no regrets” or “win-win” options) again in the manner indicated earlier.

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44. For example, if we use the externality values suggested by the California Energy Commission ($26/ton for CO\(_2\), $14,483/ton for NO\(_x\), $7,425/ton for SO\(_2\), and $57,620/ton for TSP), then estimated benefit of reducing electricity demand by 1 mwh is $23 for CO\(_2\), and $74 for the reduction of NO\(_x\), SO\(_2\) and TSP, i.e. a ratio of 3 to 1. (Assuming emissions rates for a coal-fired power plant meeting New Source Performance Standards.

45. For example, in one alternative (the “Treaty Alternative”), loss in GDP was estimated at 3.1 billion Kroner, and the loss of private consumption at 2.6 billion; however joint product benefits were estimated at 2.4 billion (with a range of 1.0–3.8 billion) (Alfsen, Brendemoen, and Glomsrod 1992, p. 28).
Suppose Figure 2–7 depicts the situation for an industrial country, say the United States. Suppose that indeed Nordhaus is correct in his estimates that the benefits to the United States are rather small. If MB$_1$ were true, then the optimal policy would be only to implement the win-win policies—demand side management, more efficient end-use devices, economically efficient pricing, and the like. If MB$_2$ were true, for the U.S. perspective, then perhaps only small emissions reductions are warranted. We assume, of course, an appropriate adjustment for the evaluation of the benefits of the reduction of joint costs.

However, the benefits to the rest of the world of emissions reductions are likely to be much higher: and hence the curve MB$_w$ lies as shown, far above the MB$_1$ and MB$_2$ curves. Therefore, when global benefits of emission cost reductions are taken into account, the optimum level of emissions reduction shifts to the right, as shown. How one persuades decisionmakers in the United States (and in other industrial countries) to take a global perspective is the main question.

Consider now the situation for a developing country (Figure 2–8). Again the global benefits curve lies far above the curve for an individual country. Evidence from empirical studies suggests that a far larger portion of the MC curve is in the no-regrets zone. Several multicountry studies point to the same result.

46. In Figure 2–7 we have drawn, for clarity, only a single marginal cost curve (MAC). It is quite possible, however, that different countries will also have different marginal cost curves (although the differences in costs are likely to be smaller than the differences in benefits).

47. For example, studies by Burgess (1990) and by Larsen (1993) address the impact of eliminating price subsidies: they estimate the level of reduction in GHG emissions by application of assumed price elasticities to the difference between the subsidized and unsubsidized price. Burgess uses the difference between actual average cost of electricity and the estimated long run marginal cost (LRMC), applies an assumed long run price elasticity of -1, and estimates the reduction in GHG emissions for eleven countries, including the United States, China, India, and some small developing countries such as Tanzania and Peru. Not surprisingly, the bulk of the total carbon emission savings of 124 million tons/year (mtpy) come from coal fuel savings, of which India accounts for 11.9 mtpy, China 26.6 mtpy, and the United States 85.4 mtpy.

Larsen does the same analysis but from the perspective of fuel prices, applies estimated own- and cross-price elasticities for the different fossil fuels to the difference between an appropriately adjusted border price and the domestic subsidized fuel price, and, more significantly, includes the countries of the former USSR and Eastern Europe. In this analysis, the former USSR (917 mtpy) and Poland (105.2 mtpy) dominate the results; indeed, the combined estimated impact in India (54 mtpy), and China (45.4 mtpy) together is less than that for Poland.

48. GEF has recently introduced the term “Type I project” for those in which operate in the range AC (i.e. for which national economic benefits are greater than national costs), and “type II project” for those in
The difference between optimal level of reduction from the national perspective, and that from the global perspective, lies at the heart of the practical problem of implementation. A related but different issue—related to equity—concerns one of the premises of CBA, namely that sunk costs and past actions are not relevant. Yet developing countries argue that in the case of the climate change problem, past emissions are relevant, because it is the industrial countries, not the developing countries, that have accounted for the bulk of the manmade GHGs present in the atmosphere.

**Systemic Evaluation**

The above results for Sri Lanka also point to the importance of systemic evaluations: the cost per ton of avoided emission for both wind and the no coal option are much lower than those estimated by others, for the exact same technology (see Table 2–3). The answer, of course, lies in the fact that the incremental cost of, say, wind power, depends upon what technology is being substituted: and these will be very different from case to case. For example in Sri Lanka, imported coal baseload plants largely determine the future system expansion cost. This is much more expensive than in India, which has available relatively large quantities of low cost domestic coal. Similarly in the generic cost estimates made by GEF for no coal options, the presumed substituting fuel is domestic oil or gas, not imported oil (as is the case for Sri Lanka). The point is that there likely exist very large, country-specific variations in the estimates of the cost of GHG emissions abatement through given technologies. Joint costs and benefits that are local in nature will very likely vary even more from place to place.

Another way of making the same point is by noting that single point cost estimates for many technologies can be quite meaningless, because the supply curve for even an individual technology is not flat. For example, as shown in a recent study of wind and hydro for India. The supply curves have the expected classical upward sloping shape as illustrated in Figure 2-9 for the supply cost of wind farms in India. Such static cost curves neglect the counterargument that in a more dynamic analysis, cost may decline due to economies of scale and technological advances.

**Issues**

**Risk, Uncertainty, and Irreversibility**

Our knowledge about how anthropogenic emissions of GHGs affect global temperature, what kind of effects a change in global temperature may have, and how efforts to mitigate climate change may work is clearly restricted. How different GHGs react in the atmosphere are not fully understood, and exact predictions of the average increase in global temperature will have different regional effects which are exceedingly difficult to foresee, even if the effect on the average temperature were taken as given. There is also considerable uncertainty about the economic and social effects of abatement measures, which are decisive for the costs and benefits of the measures.

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50. However, because of the presence of joint products—each represented by a different dimension in the multidimensional trade-off space—such valuations that look only at two dimensions need to be interpreted with some caution.
One cannot, therefore, evaluate climate measures without taking these uncertainties into account. On the other hand, acknowledgment of vast uncertainties should not lead to an inert attitude, but rather to develop rational strategies for how to act under uncertainty. Economic analysis under uncertainty aims at developing strategies for decisionmakers that face uncertainties in their future costs and benefits. The uncertainty in the outcome of a variable is often described by a probability attached to each possible outcome. In some cases the probability distribution is objectively presented, in which cases one normally talks about risk. More often, subjective probability distributions are assumed, in which cases one talks about uncertainty.

In the section, Cost-Benefit Analysis in the Context of Climate Change, we noted that the level of uncertainty in the benefits curve is greater than the level of uncertainty in the cost curve (recall Figure 2–4). Figures 2–10a – 2–10c illustrate the practical consequence of uncertainty in a different way. In Figure 2–10a, the level of emissions reduction, R(min), is based purely on a scientific assessment. Since the obligation to avoid harm is absolute, so the cost of avoiding harm is irrelevant: the benefits of control are so large that inspection of costs is unhelpful. This can be termed the absolute standards approach.

In Figure 2–10b, the level of emissions reduction, R(min)' is based on the recognition that avoiding harm does not impose an "unacceptable cost," an approach that is termed the safe minimum standards approach. Clearly one of the difficulties is that "unacceptable cost" is a concept that has no absolute definition.

Finally, in Figure 2–10c, the optimum level of emissions reduction is defined in terms of the CBA framework presented in this chapter, R(opt), is given by the point at which MB=MC. If cost abatement and damage functions were known with certainty, or if in the absence of risk aversion, one were to use expected values of the uncertain cost abatement and damage functions, then the optimum degree of emission reduction is as shown at R(opt). However, given uncertainty in the damage function, risk aversion leads one to a "precautionary" approach—R(opt)x—which requires more stringent emission reductions, lying to the right of the expected value, and roughly determined by the intersection of the cost curve and some notional upper envelope estimate of the damage function (as indicated by C in Figure 2–5). This may be somewhat closer to the point R(min)' indicated in Figure 2–10b.

The attitude towards risky outcomes is often expressed in terms of a risk premium, which is the minimum compensation required to accept a lottery with expected return x to a certain return of x. Such a premium may be required because the decisionmaker prefers certain to uncertain outcomes, but may also occur if the net benefit of his investment is non-proportionate in quantity. For instance, suppose a country commits itself to reduce emissions by 100 tons, and considers two alternative measures. One alternative reduces emissions by 100 tons with certainty. The other measure has a 50 percent chance of reducing them by 100 tons. Even if the expected reductions are equal, it is evident that a decisionmaker will prefer the certain alternative unless the uncertain alternative is considerably less costly, as there is a chance of having to impose additional measures if unlucky. Assessments of the uncertainty involved in the analysis of climate change may therefore be of great importance to decisionmaking.

However, given the uncertainty it is also important to emphasize that some actions will be less attractive than others. The mirror of the above argument is that some actions may be acceptable even with negative net expected benefit if they reduce the
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uncertainty. One way to do so is to spread the risk among several measures. Then, if one fails to meet its expected target, another may satisfy the achievements that were expected. The total risk would thus be lower than if all efforts were concentrated on one single measure.

One is scarcely able to account for all the uncertainties involved when analyzing climate change. In some cases it may be equally difficult to assess a probability distribution of a variable as a single expected estimate. Ignorance about certain effects of a measure indicate that they should be left out of the analysis. However, CBA may be of great help to decision-making even when limited to effects on which reasonably well-founded value-estimates can be provided.

One issue that has attained a lot of interest in the literature of environmental economics is the problem of irreversible decisions under uncertainty. The reason is that environmental effects, such as climate change are regarded as irreversible. If the effects turns out to be worse than expected, the world is stuck with a permanent, perhaps unwanted, climatic change, which clearly is worse than if the climate could be reestablished after such a change.

In order to incorporate the cost of irreversible effects in the CBA, a vast amount of information is required—such as how the uncertainty evolves over time. Such information, is rarely available, but we may assume that increased knowledge about climate change will narrow the range of uncertainties in the future. If so, it has been shown that one extra cost of irreversible effects is the so-called quasi option value. This value can be interpreted as the value of keeping future options open, and suggests that decisionmakers follow flexible strategies when faced with uncertainty.

The strategy that leaves most future options open is, however, difficult to determine. Investing in abatement of climate change opens possibilities for increasing emissions at a later stage if the effects turns out to be less serious than expected. On the other hand, it reduces the potential use of adaptation. In addition, it is difficult to predict the effect of increased knowledge, especially whether the outcomes become more certain. When dealing with many of the effects of climate change, ignorance is perhaps a more appropriate concept than uncertainty. Increased knowledge may change ignorance to uncertainty, but the range of possibilities will not necessarily narrow for that reason.

In applying CBA to the global climate change problem, and in particular to the evaluation of alternative policies to optimize net benefits, there are several major sources of uncertainty that need to be considered.

1. Uncertainty over the actual rates of emission. Most of the many studies cited earlier make assumptions about current and future rates of emissions in some "business-as-usual" case as a starting point. Current CO2 emissions from fossil fuel use may be reasonably well known, but the level of uncertainty increases as one considers levels of possible fossil fuel use in the more distant future, the impact of deforestation, or...
the emissions of other GHGs such as methane.\textsuperscript{55}

2. **Uncertainty over the costs of emissions reduction.** Again there are significant differences between estimating the costs in electric utility systems (relatively well known for conventional technologies) and those elsewhere, particularly for reforestation.

3. **Uncertainty about scientific linkages.** As already noted in the section, Unique Features of Climate Change, there exists a chain of scientific uncertainty (see Figure 2–3). The extent to which these uncertainties can be resolved by further research is itself subject to uncertainty (especially in light of the previously noted fact that by its very nature, \textit{ex ante} verification of models by actual data is difficult. Thus it is unclear that similar arguments invoked in the context of other environmental problems have validity for global climate change. For example, the argument that further research was necessary on an understanding of atmospheric chemistry, or of the chemistry of lake acidification, or of the exact nature of the damage mechanisms on forests, before very costly efforts are undertaken to control SO\textsubscript{2} and NO\textsubscript{x} emissions, did at least have the merit that data on the actual damage of acid rain could be found.

4. **Uncertainty in valuing the costs and benefits of the physical impacts.** Here there may exist quite large variations in the level of uncertainty: for example, evaluating the cost of protective dikes to protect against sea level rise, or of estimating the opportunity cost of inundated land is subject to significantly less uncertainty than estimating the impact on agriculture, or on biodiversity. However, estimating the costs of more extreme climate (e.g. more intense storms) will be very difficult.

5. **Uncertainty about the assumptions underlying policy options.** For example, a number of studies have estimated the impact on GHG emissions of eliminating subsidies on coal, or on electricity, using assumed values of price elasticity.\textsuperscript{56} General equilibrium models require all kinds of assumptions about the elasticities of substitution, whose actual values used in the numerical simulations are either based on historically estimated elasticities, or upon the judgment of the modeler. In either case there is uncertainty about the extent to which such values match actual behavior.

6. **Uncertainty over the effectiveness of policies.** For example, the proposition that a certain level of carbon tax will in fact result in the hypothesized fuel substitution makes a number of assumptions about the functioning of markets. As noted earlier, the very fact that many apparently “no regret” options are not being implemented suggests a higher level of market imperfection than economists like to admit, and/or substantially higher transaction costs or discount rates.

7. **Uncertainty about joint benefits and costs.** As noted earlier, joint benefits and costs may be a very significant factor in evaluating options for GHG abatement. However, these joint benefits and costs are also subject to significant uncertainties (and also measurement problems).

\textsuperscript{55} This issue is made more complicated by the fact that much deforestation is presently driven by the need to expand pasture land, which in turn implies higher methane emissions from livestock.

\textsuperscript{56} For a full discussion of uncertainty in emissions, see e.g. Ebert and Karmali (1992).
The application of valuation techniques is difficult even where the impacts themselves can be quantified with relative confidence. But in the case of global climate change, however, uncertainties in economic valuation techniques may be significantly smaller than the scientific uncertainties that surround the impacts of increasing concentrations of GHGs. Advocates of immediate mitigation action to reduce emissions argue that even if the probability of some of the important impacts are unknown, and subject to great uncertainty, they are not zero. Low probability, high impact events are especially complex to model, and may also elicit counterintuitive public reaction due to extreme risk-averse behavior (e.g. nuclear accident). Further, the process of climate change, once underway, will be irreversible (at least during a period measured in centuries), and the damages which may result are so catastrophic, that action may be warranted even in the absence of more precise scientific knowledge about the impacts.

A good analogy is a nuclear power plant accident. The Chernobyl incident notwithstanding, the risk of catastrophic accident is extremely small. But the cost of a major accident is undoubtedly very large. Both the probabilities, as well as the cost of the impacts, are very difficult to estimate. But even if one could agree on appropriate values to use, and one were able to calculate an expected value, decisionmaking on the basis of the expected value may still not reflect the preferences either of the public or of decisionmakers. The consequences of even an extremely unlikely event may be perceived as so undesirable (especially in the case of extreme risk aversion), that "normal" decision rules may simply not be viewed as appropriate. In other words, cost-benefit analysis must deal not just with expected values, but also with risk preferences of the decisionmakers, and those they represent. The traditional and simple way of incorporating uncertainty considerations in CBA has been through sensitivity analysis. Using optimistic and pessimistic values for different variables can indicate which variables will have the most pronounced effects on benefits and costs. While sensitivity analysis need not reflect the probability of occurrence of the upper or lower values, it is useful for determining which variables are most important to the success or failure of a project (Dixon et al. 1988). Indeed decision-makers often assign (even if only implicitly) probabilities to the various outcomes. Admittedly, the sheer magnitude of the costs of catastrophic climate change will make the sensitivity analysis problematic.

One might note that for certain types of uncertainty, something akin to risk insurance is available in the form of futures and options markets. For example, one can hedge against uncertainty in the future price of oil by transactions in the oil futures markets, but their efficient functioning depends upon there being some balance between those who are buyers of oil (who are primarily interested in protecting themselves against a rise in the price), and sellers of oil (who are interested in protecting themselves against a fall in the price of oil) (see Box 2–2).58

Finally, extreme uncertainty might also influence the nature of the economic instruments employed for policy purposes. For example, a price-oriented mechanism (such as a carbon tax) which limits economic dislocation might be preferred over a quantity-based mechanism (such as tradable permits) in a situation where there are both

57. See note 46, supra.

58. The U.S. Nuclear Regulatory Commission has made repeated attempts to establish probabilities for specific kinds of accidents through a technique known as fault tree analysis. Despite the appearance of scientific rigor, the resultant probability estimates remain highly controversial. For examples of the use of cost-benefit analysis by the US NRC, see e.g. Mubayi et al.(1991) or Abrahamson et al. (1989).
Box 2-2: 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 foregone 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. However, investment in reductions now is not free: resources have to be diverted from other uses, and better emission technologies may be available in the future. Thus to some extent, committing now to current technology restricts the option to use better technology later. 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.

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.
4 L. 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).
uncertain control costs and an uncertain environmental response (see Lave and Gruenspecht 1991).59

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.60 For nonmarketed 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 GHGs 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 decisionmaking. 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. Decisionmakers 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 best to achieve given levels of emission reduction reductions. Valuation issues generally do not arise in this category.

59. Precautionary expenditures may also be influenced by aversion to catastrophic risks. A recent example is the hundreds of billions of dollars per year spent in the United States to avert Soviet nuclear attack.

60. 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.
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.\textsuperscript{61} 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 United States as a whole, but significant regional variations.\textsuperscript{62} Some of the costs of adaptation will vary, depending on \textit{ex ante} actions (e.g. more agricultural R&D expenditure to develop drought or saline resistant crops).\textsuperscript{63}

4. Costs (and Benefits) of Nonadaptation. 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 dikes 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 2–4 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 nonuse value (NUV).\textsuperscript{64} 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).\textsuperscript{65} 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 nonuse value is existence value (EV). Thus

\begin{itemize}
\item 61. 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).
\item 62. It should be noted that the distinction between a mitigation measure and an adaptation measure.
\item 63. “Preliminary results suggest that although U.S. 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.
\item 64. 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 relocated.
\item 65. For further details, see Munasinghe (1993) and Pearce and Warford (1993).
\end{itemize}
$\text{TEV} = \text{UV} + \text{NUV}$
or
$\text{TEV} = (\text{DUV} + \text{IUV} + \text{OV}) + \text{NUV}$

Figure 2–11 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 rain forest) of the environmental resources underlying the perceived value, are provided. Option values and nonuse 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 2–3). 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 concepts of value.66

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.67 As shown in Box 2–3, 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.

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.68 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

66. 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).

67. For a recent overview of techniques suitable for valuing environmental costs and benefits, especially in developing countries, see Munasinghe (1993).

68. 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.
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 since past decisions cannot be changed, they have no bearing over decisions regarding the efficiency of resource use that are to be made in the present or in the future. 69

69. Contingent Valuation methods in particular are somewhat controversial, and need great care in their application to produce credible results.
Box 2-3: Taxonomy of Valuation Techniques

<table>
<thead>
<tr>
<th>TYPE OF BEHAVIOR</th>
<th>TYPE OF MARKET</th>
</tr>
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<tbody>
<tr>
<td>effect on production</td>
<td>travel cost</td>
</tr>
<tr>
<td>effect on health</td>
<td>wage differences</td>
</tr>
<tr>
<td>defensive or costs</td>
<td>property values</td>
</tr>
<tr>
<td>replacement cost</td>
<td>proxy marketed goods</td>
</tr>
<tr>
<td>Based on actual behavior</td>
<td>artificial market</td>
</tr>
<tr>
<td>Based on Intended behavior</td>
<td>contingent valuation</td>
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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 forgone 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 Differences: 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.

The second principle is that a discount rate is applied to future costs and benefits to yield their present values. The issue of choosing an appropriate discount rate has been discussed in the context of general CBA for many years (Dasgupta et al. 1972; Harberger 1976; Little and Mirrlees 1974; Sen 1967). 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 (Lind and Arrow 1982). We briefly discuss below, several key issues relating to discount rates—the topic is dealt with more fully in Chapter 1 of this volume.

Compared with most other economic investment decisions, the time perspective of measures aiming at mitigation of climate change is considerably longer. Cline (1992) suggests a 200–300 years time horizon for climate policy decisions, while investments in economic activities seldom need more than a 25 years horizon. This makes assumptions about how the economic and the environmental systems will develop, and the discounting of values that occurs in the future critical to the evaluation of measures.

The discount rate denotes the social opportunity cost of capital. It reflects total social benefits if one unit of present output is withdrawn from consumption and instead is invested (for instance in production or abatement). The criteria for optimal social and economic development is that the marginal total benefits from the different investments should be equal regardless of what the investments are aiming at. In other words, the social discount rate should be equal for all investments. If not, it would be possible to reallocate resources and attain a higher social benefit without any cost. Thus, the discount rate expresses a condition for dynamic (or intertemporal) efficiency.

The discount rate also provides a signal to decisionmakers who evaluate single projects or measures to take decisions in accordance with dynamic efficiency (over time). Even if one accepts the requirement to apply the same discount rate for marginal projects within a given time period, there are many potential optimal levels of the discount rate. This level depends, inter alia, on the social preferences about present versus future consumption which may be reflected by an intertemporal welfare function. The formulation of this function has been the subject of an extended debate in which questions about intertemporal comparisons as well as current welfare contributors have been raised.

It is worth emphasizing that although externalities related to climate change will affect the social rate of discount, it is not sufficient to merely adjust this discount rate in order to take full account of climate change in a CBA. One must include also the "price" of the environment, which may increase substantially over time. As a consequence, future impacts from climate change may be quite important to present day decisions, even in "discounted terms": A 5 percent increase in the price of the environment will fully counteract the effect of a 5 percent discount rate.

To conclude, discounting is necessary in order to compare costs and benefits at different time periods. Attempts to avoid discounting or to apply a different discount rate for climate measures than other investments will inevitably result in an inefficient policy. However, it is difficult to pick out the correct level for the optimal social rate, as there are no practical observations of such a rate. Furthermore, discount rates may depend on the future scenario that is assumed, and could vary over time—in particular very long term discount rates may be lower as economic growth rates saturate and decline.70

70. One needs to take note also of the fact that this principle is also not universally accepted, particularly by political leaders. The principle that "past sacrifices
CBA and Equity

The benefits and costs of climate change mitigation strategies may accrue to different countries (and to different regions within larger countries). How one reconciles these differences is therefore one of the central dilemmas facing policymakers.

Thus, while CBA can provide answers on who should engage in how much abatement based solely on the criterion of maximizing economic efficiency, it must be recognized that some deviation from the global least-cost solution as obtained by CBA may have to be accepted in order to get international agreement. As indicated earlier in Figure 2-1, there will likely be a trade-off between equity objectives and economic efficiency: CBA can help define the trade-off curve, but it cannot provide an answer to what combination of economic efficiency and equity is necessary to get international agreement. However, whether there is a trade-off between equity and efficiency (and the properties of this trade-off) depend upon what policy instruments are available. For example, if one permits side-payments (in lump-sum form) between countries, the efficient allocation of emissions across countries could be achieved independently of the equity issue.

Several concerns shape equity perceptions and the ability to obtain international agreements. Effective action to control climate change is dependent on a degree of international agreement. Therefore a first obstacle to whatever mechanism might be agreed upon is national sovereignty—to what extent will sovereign nations subject themselves to enforcement actions by others? Even simple agreements for joint implementation of projects involving two countries have run into difficulties (see below).

The second obstacle is the heterogeneous nature of the effects of greenhouse warming. Although the most widely cited measure of climate change is the average increase in global temperature, climate change affects different countries differently. In addition, the costs or response measures and their economic implications vary greatly among countries, particularly as a function of the level of development. Therefore the perceptions of benefits of global cooperation will differ greatly.

A third obstacle is posed by strategic incentives. If some countries take the lead and set up a GHG agreement, others have an incentive to free-ride and abstain from joining, as they cannot be excluded from the benefits such an agreement creates. If countries act selfishly in this way, few will become party to an agreement. Most countries will therefore not cooperate and no general agreement will be reached even if all countries were to benefit from it. (This is the well-known prisoner’s dilemma from game theory.)

Some argue that the overwhelming historical contribution to the buildup of GHGs from developed countries constitutes an “environmental debt,” that cannot be conveniently ignored using the traditional “sunk cost” approach. If past contributions to GHG emissions are considered from an equity viewpoint, establishment of appropriate side-payment mechanisms from developed to developing countries, including financial assistance and technology transfer, could facilitate the more enthusiastic cooperation of developing countries in climate change mitigation efforts.

71. For a discussion, see Munasinghe (1993).
2. Applicability of Techniques of Cost–Benefit Analysis to Climate Change

The question of joint implementation illustrates the limits of CBA in this regard. The motivation for joint implementation is a straightforward result of CBA. If a country—say the United States—decides to make an effort to reduce GHG emissions, and if reductions can be obtained at lower costs abroad, then the United States should initiate projects in other countries in order to minimize overall costs (Aaheim 1993). The receiving country has nothing to lose if the additional cost of such a joint implementation project is covered by the investing nation. Yet many countries and organizations have reacted with skepticism, for reasons that are political, and based on equity concerns, rather than on economic efficiency. The reasons include the mistrust of the true willingness of the industrial countries to mitigate climate change; the belief that the ultimate reduction in GHGs under such a regime would be negligible; and the suspicion that joint implementation gives industrial countries an opportunity to “buy themselves out of their problems” at the expense of the developing countries. Indeed, some developing countries fear that joint implementation investment might partly substitute for traditional forms of financial and donor assistance, and that such agreements might preclude the right of future generations to emit GHGs.

Brazil and other countries have advanced a further reason for host country skepticism of joint implementation projects, namely that Annex I countries to the Rio Convention would invest in all of the low cost/high return projects, and thus non-Annex I countries required to curb emissions would find the cheapest and best options already taken up. Such an extension of non-Annex I parties’ commitments, to higher income developing countries has recently been proposed by Australia at INC 10.

Multicriteria Analysis

Even the staunchest advocates of cost-benefit analysis would concede that economic efficiency (or economic value) is not the sole criterion in setting public policy, and that policymakers rightfully need to consider a broader set of objectives. Unfortunately there is much confusion about what constitutes a coherent set of objectives. Table 2–5, taken from a major EPA study, lists the criteria suggested there as constituting the basis for selecting public policy; the authors go on to note that the first four criteria listed—flexibility, urgency, irreversibility, and low cost—“...would generally be given the highest priority.” Note that many of these criteria overlap with each other, and economic efficiency is among them!

Simple applications of CBA tend to focus only on economic efficiency. However, in more recent extensions, traditional CBA concepts are embedded in MCA, that expressly allows more than one objective, and expressly addresses risk and uncertainty—thereby providing an integrating mechanism for most of the criteria listed. Multicriteria analysis techniques first gained prominence in the 1970s, when the intangible environmental externalities lying outside conventional cost-benefit analysis (CBA) methodologies were increasingly recognized. It also met one objective of modern decisionmakers, who preferred to be presented with a range of feasible alternatives—as opposed to one “best” solution. MCA also allows for the appraisal of alternatives with differing objectives and varied costs and benefits, which are often assessed in differing units of measurement.

72. However, for a criticism of this argument, see e.g. Brown (1992), who points out that some European countries have already taken unilateral action to reduce GHGs, in hopes that others will follow. Moreover, other game theory paradigms have been proposed for modeling international environmental negotiations: for example, Carraro and Siniscalco (1992, 1993) propose a “chicken game” framework belonging to the class of coordination games.
Thus, upon closer examination of the criteria listed on Table 2-5, criteria 1, 2, 3, 4, 5, 6 can all be treated by modern decision-analysis: indeed, questions of timing (urgency), flexibility (or robustness), capital constraints ("low cost") are all central elements of the approach. Criterion 13 is really part of 6. (In the text the authors of the EPA report amplify the criterion 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 report (p. 393), "if the principal costs and benefits can be quantified in monetary terms, economic theory provides a rigorous procedure for making trade-offs between present and future costs, and for considering uncertainty, profitability, and most of the other criteria."

There is also a need to separate the basic goals of public policy—such as economic efficiency and equity—which surely have primacy, from implementation issues such as legal and administrative feasibility, which are generally secondary. The premise of CBA analysis is that one looks first at the primary objectives, and then asks how much of the primary objectives one may have to sacrifice to achieve practical implementation. This principle has become accepted in many areas of policymaking. For example, the starting point for setting electric utility rates is to calculate the economically efficient tariff (based on marginal costs), and then make adjustments to protect low income groups (through lifeline rates, special provisions for disconnection in the event of nonpayment, etc.). The essence of the approach is not that noneconomic issues are ignored, but that the trade-offs between economic efficiency and equity (or indeed other objectives not readily monetized) are explicitly quantified and displayed in such a manner that decisionmakers are made aware of how much of one objective is traded off in the interests of the other.

Indeed, one of the advantages of MCA is that it forces political decisionmakers to look at the trade-offs between their major objectives, rather than attempting to boil down everything into a single number, particularly where valuation techniques may be controversial. Nowhere is this more important than in valuation of human life.\(^7\)

The application of MCA methods involves the following steps:

1. Selection and definition of attributes, say \(A_i, i=1,\ldots, N\), selected to reflect important planning objectives. While the two major relevant attributes in the context of the global climate change problem are cost and GHG emission reductions, we have already noted that strategies to control GHG emissions may have other side-effects, some positive, and some negative, which may also difficult to value, and which might therefore require additional attributes (such as, for example, for biodiversity)

2. Quantification of the levels \(A_y\) of the \(i\) attributes estimated for each of the \(j\) alternatives. In this quantification, full consideration must be given discounting issues, for noneconomic and economic attributes alike. At this stage of the analysis, trade-off curves are powerful tools to communicate with decisionmakers: they are particularly relevant in a situation, such as the climate change problem, where the quantification of benefits may be difficult, and where decisionmakers must act largely on the basis of trading off short-term costs against certain levels of GHG emission reduction.

\(^7\) For a discussion of these issues, and a discussion of how CBA can make a contribution to the evaluation of such projects, see Aaheim (1993). Concerns about "market justice" and related considerations are outlined in Rose (1990).
3. Determination and application of a decision rule, which amalgamates the information into a single overall value or ranking of the available options, or which reduces the number of options for further consideration to a smaller number of candidate plans. Where amalgamation is contemplated, attribute levels are first translated into a measure of value, \( v_i(A_{ij}) \) (also known as the attribute value function).\(^{74}\) This is sometimes combined with a normalization procedure usually on a scale of zero to one (in which the lowest value of the attribute value function is assigned zero, the highest one). Subsequently weights \( w_i \) for each attribute must be determined to arrive at the overall amalgamation.

Trade-off curves are a particularly useful tool for analysis of energy-environmental policy options. Figure 2-12, taken from a recent study of options for GHG emission reductions in Sri Lanka (Meier, Munasinghe, and Siyambalapitiya 1993), illustrates the essential concepts. The figure is a plot of two attributes—GHG emissions and total system costs—for the technology options identified on Table 2-6. Each point represents a perturbation of the reference case, defined as the official 1993 base case capacity expansion plan of the CEB.

The *trade-off curve* is the set of options that are not dominated by others (sometimes referred to as the "noninferior set"). These are the options that are "closest" to the origin, and therefore represent the "best" set of options that merit further attention.\(^{75}\)

Several useful concepts arise here. First is the concept of *dominance*.\(^{76}\) PFBC (a clean coal technology) is said to dominate the options in the sector shown, namely FGD, wind and *FGD*. PFBC has better costs and better (lower) GHG emissions, and is thus preferred over these options under both criteria. If only these two attributes mattered, then there would be no reason to select any of the dominated options in place of PFBC.

Another perspective is gained by dividing the solution space into quadrants with respect to the reference case (Figure 2–13). The options that fall into quadrant III are the "win-win" options, which are better than the reference case in both attributes. In this case, mini-hydro, energy efficient refrigerators, T&D system loss reduction and compact fluorescents all fall into this quadrant, providing both cost and emission gains. Such win-win solutions were mentioned earlier, in the section, Cost-Benefit Analysis in the Context of Climate Change, in connection with the empirical estimates of the MAC curves (e.g. Figure 2–5): these "below-the-line" options in the MAC curves are equivalent to the options in quadrant III of a multi-attribute analysis.\(^{77}\)

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74. Differential valuation of human lives is strenuously opposed by some: if a U.S. life is worth $1.5 million, then so is everyone else. On the other hand, when making comparisons of per capita GDP, economists are increasingly turning to purchasing power parity adjustments in an attempt to make more valid comparisons of economic level. MCA avoids these difficulties by removing judgments about the value of human life from the domain of technical assessment, into the domain of political decision-making, where making such judgments properly belongs.

75. MCA deals with attitudes toward risk and uncertainty at this stage by the use of multi-attribute utility functions, which explicitly capture attitudes toward risk (see Keeney and Raiffa 1976 and Keeney and Wood 1977 for an application in water resource planning, or Keeney and von Winterfeldt 1987 for application to electric utility planning).

76. We note also that the trade-off analysis and surfaces will be much more complex as the number of attributes increases.

77. 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 decisionmaking.
Finally one should note that MCA leads to implicit valuations whenever two options are compared. For example, in the case of Figure 2–13, a decisionmaker who prefers option “Y” (“max hydro+no coal”) to point “X” (“NoCoal+lowSoil”) makes an implicit valuation of the concomitant reduction of GHG emissions in terms of the increased costs (i.e. equal to the slope of the trade-off curve between X and Y, about $200/ton of CO₂).78

It must be noted that the choice of criteria in a MCA will depend upon each country’s short- and long-term development plans. Despite a common global objective of stabilizing atmospheric concentrations of GHGs, developing countries may use different criteria because of immediate or urgent needs to ensure food supplies and service debt requirements. Consequently different countries may place different weights upon the attributes.

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 decisionmaking 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. The writing team defined the modern CBA approach more broadly to encompass a family of decision analysis techniques that includes cost-effectiveness analysis, multicriteria analysis and decision analysis, in addition to traditional cost-benefit analysis. This modern CBA provides a promising set of techniques with which to analyze climate change issues.

In the introduction we noted that there were four essential questions facing decisionmakers 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. As noted in earlier sections, however, particularly the marginal damage costs are sometimes very difficult to estimate.

It also 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 also 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 straightforward 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 the section, Cost-Benefit Analysis in the Context of Climate Change (see e.g. Box 2–2), recent developments have begun to deal with the question of timing, particu-

78. 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.
larly 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, and is directly addressed by CBA. As we have seen (for example in Figure 2-5), 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 2-7), also necessarily require explicit consideration of specific policy or technology options. The clear economic analysis and identification of the most cost-effective abatement options using CBA is critical for practical policymaking.

None of the family of techniques considered can themselves resolve the fourth question—which involves equity—but they do 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. 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 framework for identifying the essential questions that policymakers must face when dealing climate change. The CBA approach forces decisionmakers 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 multicriteria analysis, permit some quantitative expression of the trade-offs to be made.

Decision analysis also provides many insights to how one should deal with the considerable uncertainty. Flexible policies are essential when faced with large uncertainties. However, increased knowledge may narrow uncertainty, but the range of options may not necessarily increase.

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 establishes a framework to gather information for the decisionmaking process, and forces an approach to decisionmaking that is based on rigorous and quantitative reasoning.
Table 2-1: Estimates of the Impact of Climate Change (billions of 1988 dollars)

<table>
<thead>
<tr>
<th></th>
<th>Nordhaus</th>
<th>Cline</th>
<th>Fankhauser</th>
<th>Other</th>
<th>Fankhauser</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavily affected sectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture</td>
<td>1</td>
<td>15.2</td>
<td>7.4</td>
<td>1.2</td>
<td>39.1</td>
<td>12.3</td>
</tr>
<tr>
<td>Coastal areas</td>
<td>10.7</td>
<td>2.5</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>0.5</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other sectors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wetlands and species</td>
<td></td>
<td>7.1</td>
<td>14.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health and amenities</td>
<td></td>
<td>8.4</td>
<td>30.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>38.1</td>
<td>11.2</td>
<td>12.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>50.3</td>
<td>53.4</td>
<td>66.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL as % of output (GDP)</td>
<td>1</td>
<td>1.1</td>
<td>1.3</td>
<td>1.5</td>
<td>2.8(a)</td>
<td></td>
</tr>
</tbody>
</table>

Blanks denote not available.


Table 2-2: Impact of Welfare Losses of GHG Abatement Options in Sri Lanka (in $/ton of avoided carbon)

<table>
<thead>
<tr>
<th></th>
<th>No coal</th>
<th>Wind</th>
<th>CFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply cost impact</td>
<td>16</td>
<td>67</td>
<td>-472</td>
</tr>
<tr>
<td>Consumer impact</td>
<td>10</td>
<td>66</td>
<td>-66</td>
</tr>
<tr>
<td>TOTAL</td>
<td>26</td>
<td>131</td>
<td>-538</td>
</tr>
</tbody>
</table>


Notes: Negative numbers indicate a benefit.
CFL = compact fluorescent lighting.

Table 2-3: Comparisons of Cost Estimates for CO₂ Abatement (in $/ton of CO₂)

<table>
<thead>
<tr>
<th></th>
<th>Study type</th>
<th>Wind</th>
<th>No coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sri Lanka</td>
<td>systemic, single 300Mw windfarm</td>
<td>67–131</td>
<td>16–26</td>
</tr>
<tr>
<td>GEF</td>
<td>generic</td>
<td>116–223</td>
<td>45–89</td>
</tr>
<tr>
<td>India</td>
<td>supply cost</td>
<td>150–600</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2-4: Potential Impacts to Be Valued (for the U.S.)*

<table>
<thead>
<tr>
<th>Systems</th>
<th>Potential impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forests/</td>
<td>migration of vegetation</td>
</tr>
<tr>
<td>Terrestrial vegetation</td>
<td>reduction in inhabited range</td>
</tr>
<tr>
<td></td>
<td>altered ecosystem composition</td>
</tr>
<tr>
<td>Species diversity</td>
<td>loss of diversity</td>
</tr>
<tr>
<td></td>
<td>migration of species</td>
</tr>
<tr>
<td></td>
<td>invasion of new species</td>
</tr>
<tr>
<td>Coastal wetlands</td>
<td>inundation of wetlands</td>
</tr>
<tr>
<td></td>
<td>migration of wetlands</td>
</tr>
<tr>
<td>Aquatic ecosystems</td>
<td>loss of habitat</td>
</tr>
<tr>
<td></td>
<td>migration to new habitat</td>
</tr>
<tr>
<td></td>
<td>invasion of new species</td>
</tr>
<tr>
<td>Coastal resources</td>
<td>inundation of coastal development</td>
</tr>
<tr>
<td></td>
<td>increased risk of flooding</td>
</tr>
<tr>
<td>Water resources</td>
<td>changes in supplies</td>
</tr>
<tr>
<td></td>
<td>changes in drought and floods</td>
</tr>
<tr>
<td></td>
<td>changes in water quality+hydropower production</td>
</tr>
<tr>
<td>Agriculture</td>
<td>changes in crop yields</td>
</tr>
<tr>
<td></td>
<td>shifts in relative productivity and production</td>
</tr>
<tr>
<td>Human health</td>
<td>shifts in range of infectious disease</td>
</tr>
<tr>
<td></td>
<td>changes in heat-stress and cold-weather afflictions</td>
</tr>
<tr>
<td></td>
<td>changes in fertility due to stress</td>
</tr>
<tr>
<td>Energy</td>
<td>increase in cooling demand</td>
</tr>
<tr>
<td></td>
<td>decrease in heating demand</td>
</tr>
<tr>
<td></td>
<td>changes in hydropower output</td>
</tr>
<tr>
<td>Transportation</td>
<td>fewer disruptions in winter transportation</td>
</tr>
<tr>
<td></td>
<td>increased risk for summer inland transportation</td>
</tr>
<tr>
<td></td>
<td>risks to coastal roads</td>
</tr>
<tr>
<td>Also considered in EPA study</td>
<td>air quality</td>
</tr>
<tr>
<td>Other impacts not considered</td>
<td></td>
</tr>
<tr>
<td>in OTA or EPA studies</td>
<td></td>
</tr>
<tr>
<td>Weather-related damages</td>
<td>damages related to changes in the frequency and severity of extreme weather events like storms</td>
</tr>
<tr>
<td>Amenity value</td>
<td></td>
</tr>
<tr>
<td>Construction industry</td>
<td></td>
</tr>
</tbody>
</table>

*Systems and potential impacts as listed in OTA, *op. cit*, p. 15.
### Table 2-5: Criteria for Choosing a Strategy

1. Flexibility
2. Urgency
3. Low cost
4. Irreversibility
5. Consistency
6. Economic Efficiency
7. Profitability
8. Political feasibility
9. Health and Safety
10. Legal and administrative feasibility
11. Equity
12. Environmental quality
13. Private v. Public sector
14. Unique or critical resources

*Source: EPA (1989).*

### Table 2-6: Technology Interventions for GHG Emissions Reductions

<table>
<thead>
<tr>
<th>Option</th>
<th>Comments</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind energy</td>
<td>305 Mw total</td>
<td>wind</td>
</tr>
<tr>
<td>Mini-hydro</td>
<td></td>
<td>miniHy</td>
</tr>
<tr>
<td>DSM: energy efficient refrigerators</td>
<td></td>
<td>EEF</td>
</tr>
<tr>
<td>DSM: compact fluorescents</td>
<td></td>
<td>CFL</td>
</tr>
<tr>
<td>T&amp;D loss reduction</td>
<td>10% T&amp;D loss goal (in place of 12%) by 2000.</td>
<td>TD+</td>
</tr>
<tr>
<td></td>
<td>12% goal delayed to 2003</td>
<td>T&amp;D-</td>
</tr>
<tr>
<td>Max hydro</td>
<td>builds both reservoirs in the Upper Kotmale project; 144Mw high dam version of Kukule.</td>
<td>maxHy</td>
</tr>
<tr>
<td>Clean coal technology</td>
<td>pressurized fluidized bed combustion-combined cycle units; assumed for all coal units after 2000:</td>
<td>PFBC</td>
</tr>
<tr>
<td></td>
<td>with pessimistic capital cost assumptions</td>
<td>PFBC-</td>
</tr>
<tr>
<td>Clean fuels</td>
<td>use imported low-sulfur residual oil for diesels (0.5% S by weight rather than 2.5% S).</td>
<td>low S oil</td>
</tr>
<tr>
<td></td>
<td>use low sulfur (0.5%) coal (rather than 1% S coal)</td>
<td>low S coal</td>
</tr>
<tr>
<td>FGD systems</td>
<td>model free to chose optimal generation mix; coal plants must have FGD systems.</td>
<td>FGD</td>
</tr>
<tr>
<td></td>
<td>FGD systems forced onto base case solution</td>
<td>**FGD</td>
</tr>
<tr>
<td>No coal</td>
<td>model free to choose least-cost combination of diesels +hydro</td>
<td>noCoal</td>
</tr>
</tbody>
</table>
2. Applicability of Techniques of Cost–Benefit Analysis to Climate Change

Figure 2–1: Multi-Criteria Analysis

Figure 2–2: Total and Marginal Costs and Emissions Reductions
Figure 2-3: The Chain of Causality

- Emissions
- Ambient concentration of GHG in atmosphere
- Temperature increase
- Physical effects (Sea level rise, etc.)
- Impact
- Economic valuation

Figure 2-4: The Marginal Cost Curve for Thailand

Source: Asian Institute of Technology (1993).
2. Applicability of Techniques of Cost-Benefit Analysis to Climate Change

Figure 2–5: Uncertainty in the Benefit Curves

![Diagram showing the uncertainty in the benefit curves with marginal cost/benefit on the y-axis and level of emissions reduction on the x-axis.]

Figure 2–6: Impact of GHG Emissions Reductions on GDP

![Diagram showing the impact of GHG emissions reductions on GDP with CO₂ emissions reductions on the x-axis and GDP on the y-axis, representing various countries and emissions reduction percentages.]
Figure 2–7: The Marginal Cost and Benefit Curves for an Industrial Country

Figure 2–8: The Marginal Cost and Benefit Curves for a Developing Country
2. Applicability of Techniques of Cost–Benefit Analysis to Climate Change

Figure 2-9: Supply Cost for Windfarms in India

Figure 2-10a: Cost-Benefit Analysis and Uncertainty: Absolute Standard Approach
Figure 2-10b: Cost-Benefit Analysis and Uncertainty: Safe Minimum Standard Approach

Figure 2-10c: Cost-Benefit Analysis and Uncertainty: Cost-Benefit Approach
Figure 2-11: Categories of Economic Values Attributed to Environmental Assets (with Examples from a Tropical Rain Forest)

Total Economic Value

<table>
<thead>
<tr>
<th>Use values</th>
<th>Non-use values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct use values</td>
<td>Indirect use values</td>
</tr>
<tr>
<td>Output that can be consumed directly</td>
<td>Functional benefits</td>
</tr>
<tr>
<td>- Food</td>
<td>- Ecological functions</td>
</tr>
<tr>
<td>- Biomass</td>
<td>- Flood control</td>
</tr>
<tr>
<td>- Recreation</td>
<td>- Storm protection</td>
</tr>
<tr>
<td>- Health</td>
<td>- Biodiversity</td>
</tr>
<tr>
<td>- Conservation habitats</td>
<td>- Endangered species</td>
</tr>
</tbody>
</table>

Existence values

Other non-use values

Value from knowledge of continued existence

* Decreasing "tangibility" of value to individuals

Figure 2-12: The Trade-Off Curve

Figure 2-13: "Win-Win" Options

2. Applicability of Techniques of Cost–Benefit Analysis to Climate Change

Bibliography


2. Applicability of Techniques of Cost–Benefit Analysis to Climate Change


2. Applicability of Techniques of Cost-Benefit Analysis to Climate Change


3. Financing Global Environmental Programs: Efficient Approaches to Cooperation and Institutional Design

Chitru S. Fernando, Kevin B. Fitzgerald, Paul R. Kleindorfer, and Mohan Munasinghe

Growing awareness and increasing concern about the accumulation of greenhouse gases (GHGs) has led to a series of initiatives—such as the United Nations Framework Convention on Climate Change (FCCC), and the Rio de Janeiro Conference in 1992—towards a global accord on the mitigation of global climate change. Modest progress was achieved in the international arena during the first conference of parties to the FCCC held in Berlin, in March–April 1995. First, delegates agreed to start a negotiating process to be concluded in 1997, that would set “limitation and reduction objectives” for all GHGs within a specified future timeframe, for Annex 3–1 countries (basically OECD and transition economies). There would be no new commitments for developing countries. Second, joint implementation or JI activities (involving coordinated GHG reductions between two countries) would be tested during a pilot phase, and then revised by the year 2000. While all countries could participate, Annex 3–1 countries would not receive any credit for GHG reductions achieved through JI activities during this pilot phase.

As in the case of the Montreal Protocol for the elimination of CFCs, an important issue associated with such the FCCC is the allocation of resources globally to achieve this mitigation in the most efficient and equitable manner. This chapter identifies several issues relating to the design of institutions to implement economically efficient and equitable approaches to monitoring and mitigating the effects of GHGs, especially carbon dioxide, on the global environment and the global economy.

A key difference between the reduction of carbon dioxide and the reduction of ozone depleting substances is that production of the latter was concentrated in the industrial world and a few large developing nations, whereas the production of other GHGs is widely dispersed and is rising rapidly in the developing world due to the heavy use of fossil fuels and forest depletion. Hence, whereas resource transfers envisaged in the Montreal Protocol were primarily driven by equity considerations and aimed at offsetting the cost of changes on the demand side, it is clear that from an efficiency standpoint, achieving global GHG reduction targets would require substantial investments to reduce the emission of GHGs in the developing world. It is also clear that the sheer magnitude of the economic impacts likely to be under discussion will be considerably higher, so that the conse-

Constructive comments from Stephen Coate, Miguel Gouveia and Howard Kunreuther are gratefully acknowledged. We also benefitted from feedback at the IIASA Workshop on Risk and Fairness (June 19–22, 1993), the University of Michigan Graduate School of Management Workshop, the University of Pennsylvania Public Policy and Management Workshop, the “Energy Environment Nexus—Indian Issues and Global Impact” Conference at the University of Pennsylvania (April 1994), and the International Conference on Energy, Environment and the Economy (Taipei, August 1994). This research has been supported by a grant from the World Bank.
quences of policies, including those directed at equitable burden sharing, will not be just "at the margin," but will entail significant changes in business-as-usual scenarios. Furthermore, the science of global climate change is fraught with uncertainties, so that issues of monitoring and mitigation and the impact of policy on these will be much more difficult to understand. Coupled with scientific uncertainty are issues of policy uncertainty related to available data, especially in developing countries, on levels of economic activity in sectors using or generating GHGs. This is partially the result of very diffuse sources and sinks for GHGs and the very large number of economic agents involved in these sectors. The forthcoming second report of the intergovernmental panel on climate change (IPCC) will help to achieve greater scientific consensus on both the physical and socioeconomic parameters of global climate change.

The bulk of this chapter is focused on the development of an economic framework to both inform the design of and to evaluate alternative institutional mechanisms for global GHG abatement. This framework is built around a group of countries or country groups with heterogeneous preferences and incomes. We investigate alternative outcomes when countries carry on with "business-as-usual" (noncooperatively), maximizing their individual welfare, allocating resources for consumption and GHG-reducing investment accordingly, and when they cooperate in global efforts to mitigate global climate change. Our focus is on seeking out opportunities for cooperation through international resource transfers and the reallocation of these resources such that all countries are made better off through cooperation. More so than in the case of the Montreal Protocol, an important element of a cooperative global solution to the GHG problem is the seeking out of projects that are the most efficient from a global standpoint, and ensuring that these projects are implemented through international resource transfers. Thus, for example, the OECD countries might find it more cost effective to invest in GHG abatement projects in developing countries, and fund a pool of resources to put such a program into effect. On the other hand, as in the case of the Montreal Protocol, transfers also play an important role on the equity dimension, since they are an important lubricant for cooperation. The framework that we develop provides a useful basis for examining alternative equity-driven "constraints" on a purely economic solution. Several of these constraints are examined in the chapter.

We proceed as follows. The next section develops the basic economic model of this chapter, a two-stage model in which countries or regions are assumed to make investments (in GHG mitigation) and monetary transfers in stage 1, before an uncertain state of the world is revealed in stage 2. We contrast two cases: (1) the autarkic case in which transfers are restricted to zero; and (2) the first-best case in which investment resources are pooled and reallocated globally, to demonstrate the impacts of cooperation. We then use this model to develop a simulation framework for illustrating the impact of alternative proposals for cooperation and burden-sharing in mitigating global climate change. In the section, Institutional Mechanisms for Implementing Global Cooperation, we discuss institutional mechanisms for implementing global cooperation, focusing on features of bilateral and multilateral schemes that have been proposed. A final section presents concluding remarks and policy implications, and discusses directions for future research.

**Modeling International Cooperation for GHG Mitigation**

In this section, we investigate impacts of alternate levels of cooperation (as manifested by resource transfers and schemes of
burden sharing) on the efficiency of GHG mitigating investments and develop a simulation framework to illustrate impacts on a regional basis. First, we provide an overview of our conceptual economic framework which enables us to compare and contrast these alternative schemes and their outcomes. We then examine the particulars of resource transfers under different constraints through an illustrative simulation framework.

**The Basic Economic Model**

We begin by developing a simple two-stage model of global interactions associated with reducing GHG emissions. A detailed development of this model is presented in Annex 3-1. Each country faces a number of trade-offs in confronting the issues of global climate change. We reflect the cost of investments in technologies or activities directed toward reducing GHG emissions by each country, \( \theta \), in a generic “GHG production function,” \( g(x(\theta), y(\theta); \theta) \). Global GHG emissions, \( G(X,Y) \), are the sum of emissions (measured in units of global climate change potential) across all countries, \( \Theta \):

\[
G(X,Y) = \sum_{\theta \in \Theta} g(x(\theta), y(\theta); \theta)
\]  

(1)

where \( x(\theta) \) is investment by country \( \theta \) to reduce GHG emissions at stage 1, \( y(\theta) \) is consumption by country \( \theta \) at stage 1, and \( X \) and \( Y \) are vectors of all country investments and consumptions, respectively. We assume throughout that, for each country, \( g(x, y; \theta) \) is increasing in consumption and decreasing in mitigation investments. We also assume that \( g(\cdot, \theta) \) is jointly convex in \( (x, y) \), so that investments, \( x \), have a declining marginal impact on (reducing) \( G \) and consumption has an increasing marginal impact on \( G \).

Resources used for reducing GHG emissions could clearly be devoted to other productive purposes in each country. The economic consequences of investments in GHG mitigation is reflected in the model as a reduction in current consumption through the budget constraint:

\[
I(\theta) = x(\theta) + y(\theta) - s(\theta)
\]

(2)

where \( I(\theta) \) is income for country \( \theta \) in stage 1 and \( s(\theta) \) is a monetary transfer payment to country \( \theta \) at stage 1. Thus, investments in GHG reduction will necessarily reduce consumption \( y(\theta) \) unless offset by transfers \( s(\theta) > 0 \) to \( \theta \) from other countries. For feasibility, we require the following balancing condition on transfers among countries:

\[
\sum_{\theta \in \Theta} s(\theta) = 0
\]

(3)

The consequences of global GHG emissions and the uncertainty of global climate change may be quite different from one country to the next. We reflect these consequences through the following aggregate welfare function, \( U(\theta) \), for country \( \theta \):

\[
U(X, Y, \omega; \theta) = V(G(X, Y), y(\theta), \omega; \theta), \quad \theta \in \Theta
\]

(4)

where \( \omega \in \mathbb{R}^* \) is an uncertain state of the world and \( U \) depends on \( X \) only through aggregate GHG emissions \( G \). We will assume that \( V \) is decreasing in \( G \), increasing in \( y \), and jointly concave in \( G \) and \( y \), so that global emissions, \( G \), have an increasing marginal impact on (reducing) welfare and consumption has a decreasing marginal impact on welfare. \( U \) may be thought of as the net economic benefits realized from the country’s activities in stages 1 and 2.

To draw some general conclusions about the welfare enhancing potential of international cooperation in financing GHG mitigation, we subject this generic framework to comparative statics. The conclusions summarize below are based on detailed analysis presented in Annex 3-1.

We analyze two cases: a benchmark noncooperative outcome based on uncoordi-
nated actions by individual countries and a first-best cooperative solution. In both cases, each country maximizes welfare (4) subject to the budget constraint (2). The benchmark noncooperative outcome is characterized by no international transfers, $s(\theta) = 0$. A first-best solution allows international resource transfers and cannot be improved upon for all countries simultaneously, i.e., it is Pareto efficient. The first-best solution is effected by putting all GHG mitigation resources in the hands of a central global authority, which is assumed to allocate them to the most cost-effective GHG mitigation projects with no transactions costs.

In the noncooperative case, each country maximizes welfare by equating the marginal loss in consumption benefits to the benefits for itself of transferring a monetary unit in that country from consumption to investment. By contrast, in the first-best solution, marginal consumption losses are equated to global benefits of increased investment in mitigating GHG emissions (see Annex 3–1). This leads to the following conclusions:

The noncooperative solution is Pareto inefficient in the sense that there are corresponding cooperative solutions that leave every country better off than under the noncooperative solution.

The level of aggregate GHG emissions achieved under any cooperative solution is efficient in the sense that it is the minimum aggregate emission level achievable from total mitigation investments.

This illustrates how cooperation is key to improving efficiency in GHG mitigation efforts. The first finding indicates that increased cooperation itself can lead to increased efficiency, with respect to both consumption and investment patterns. The second finding notes, in particular, that the most basic level of cooperation could involve simply increasing the efficiency of investments in mitigation activities by focusing on the best alternatives for GHG mitigation investments globally.

**An Illustrative Framework for Simulating Alternative Forms of Cooperation**

In the remainder of this section, we develop a simulation model to illustrate the general economic framework presented above. Since we make a number of assumptions to model country groups, the results reported in this section are indicative only and should in no way be construed as modeling the actual behavior of nations. The purpose of this simulation is to examine the relative consequences of various constraints to (or requirements for) cooperation in financing mitigation of GHG emissions. Throughout this section we maintain the assumption that GHG mitigation investments are purchased at incremental cost. This assumption is relaxed in the section, Institutional Mechanisms for Implementing Global Collaboration, when we evaluate the relative consequences of a global market through which all GHG mitigation investments are made at a single market-clearing price.

**The Simulation Model**

We assume the following specifications for the general GHG production function and the aggregate welfare function in equations (1) and (4) above:

$$g(x(\theta), y(\theta), \theta) = [\beta(\theta) + \frac{\delta(\theta)(\alpha(\theta) - \beta(\theta))}{\delta(\theta) + x(\theta)}] y(\theta)$$

(5)
\[ G(X,Y) = \sum_{\theta \in \Theta} g(x(\theta), y(\theta), \theta) = \sum_{\theta \in \Theta} [\beta(\theta) + \delta(\theta)(\alpha(\theta) - \beta(\theta))] y(\theta) \] 

and

\[ V(G(X,Y), y(\theta), \omega; \theta) = t(\theta) \log y(\theta) - h(\omega) y(\theta) G(X,Y) \] 

where \( \alpha(\theta) \), \( \beta(\theta) \), \( \delta(\theta) \), \( t(\theta) \) and \( y(\theta) \) are positive real numbers for each \( \theta \in \Theta \).

In the GHG production function (5), \( \alpha(\theta) \) is the rate of GHG production per unit of economic production and reflects the current technology and structure of the economy. Note that if the level of GHG mitigation investments, \( x(\theta) \), is zero, then \( g(\theta) = \alpha(\theta) y(\theta) \). As investments, \( x(\theta) \), rise, the rate of GHG production per unit of economic production declines geometrically toward a "best practice" rate for the economy. \( \delta(\theta) \) determines the amount of investment required to move the economy half way toward its "best practice frontier," \( \beta(\theta) \).

The aggregate welfare function (7) assumes diminishing returns to consumption and a linear GHG damage function. \( h(\omega) y(\theta) \) represents the avoided cost of damage to country \( \theta \) in state of the world \( \omega \) due to global GHG emissions, \( G(X,Y) \). We denote the expected value of \( h(\omega) y(\theta) \) by \( \bar{h} \) and the expected value of \( h(\omega) y(\theta) \) by \( \bar{\gamma}(\theta) \). Specification of parameters for (5) and (7) completely specifies the system of preferences for consumption, \( y(\theta) \), and investment in GHG mitigation, \( x(\theta) \).

Equations (5)–(7) are consistent with the maintained assumptions for \( g(\cdot, \theta) \) and \( V(\cdot, \theta) \) stated under equations (1) and (4) above. Budget constraint (2) and balancing condition (3) are maintained throughout. Analytical results for various specifications of (5)–(7) were obtained and are available from the authors. These analytical results were used to validate the numerical simulations reported below.

**Model Parameters**

We implement this simulation framework for six country groups according to income. India and China, owing to their size, are treated as a separate group as are economies in transition (countries of the former Soviet Union and Central Europe).

Parameters \( \alpha(\theta) \) and \( \beta(\theta) \) of the industrial \( \text{CO}_2 \) production function (5) have been selected for each country group, \( \theta \in \Theta \), from the emissions data displayed in Figure 3–1.\(^1\) \( \alpha(\theta) \) was selected for each country group such that industrial \( \text{CO}_2 \) emissions under the noncooperative benchmark outcome, \( g(x, y; \theta)_{NC} \), matches actual 1989 industrial \( \text{CO}_2 \) emissions. The investment required to move a group of countries half way toward their "best practice frontier," \( \delta(\theta) \), has been selected to be 1 percent of GNP for each country group. Assumptions for \( \alpha(\theta) \), \( \beta(\theta) \), and \( \delta(\theta) \) for each country group are presented in Table 3–A1. Using these values in equation (5) implies the incremental cost curves for \( \text{CO}_2 \) reductions shown in Figure 3–2. We leave refinements, such as a more accurate specification of possible cost functions for investments in GHG reduction

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1. Countries are grouped by income according to the 1991 World Development Report (World Bank 1992). Emissions data are from World Resources 1992–1993 (WRI 1992). For purposes of this simulation model, we account only for industrial \( \text{CO}_2 \) emissions. WRI (1992) also reports net \( \text{CO}_2 \) emissions from land use changes, \( \text{CH}_4 \), CFCs, and the IPCC index of combined radiative forcing potential from all of these sources.
technologies and extension to a dynamic setting, for future research.

Parameters \( t(\theta) \) and \( \bar{Y}(\theta) \) in equation (7) model relative preferences in each country group for consumption and for avoiding damage due to climate change by investing in GHG abatement. We have selected \( t(\theta) \) and \( \bar{Y}(\theta) \) for each country group, \( \theta \in \Theta \), to reflect a high priority on consumption over investment in GHG abatement, a priority that diminishes with rising income. Expectations on \( h(\omega) \) are assumed to be identical across country groups. Parameters for \( t(\theta) \) and \( \bar{Y}(\theta) \) for each country group are shown in Annex Table 3-A1.

Our assumptions for \( t(\theta) \) and \( \bar{Y}(\theta) \) of the aggregate welfare function (7) and \( \delta(\theta) \) of the industrial CO\(_2\) production function (5) are entirely arbitrary. As such, results presented in this section serve only as illustrations of the relative distributional and efficiency implications of different burden-sharing principles and forms of international cooperation.

**Conditions for Cooperation: Negotiated Reduction Targets**

A primary focus of this research is on ways in which cooperation can be achieved to enhance the expected welfare of each country relative to acting unilaterally in a fully noncooperative fashion. As we noted in the introduction, conditions for global cooperation that ensure equity are likely to be very important in order to achieve the benefits of a cooperative solution. Furthermore, in addition to being a “lubricant for cooperation,” as noted in the introduction, there are also moral arguments in favor of equitable burden sharing.

Before evaluating the performance of institutional arrangements on cooperation (the section, Institutional Mechanisms for Implementing Global Collaboration), we examine the implications of different constraints on cooperative action in financing GHG mitigation. We use the simulation framework presented above to assess how country groups are affected when several types of equity-driven conditions are imposed on the basic solutions summarized above. The development here is entirely in the spirit of asking what can be done to make all nations better off relative to the noncooperative benchmark.\(^2\)

With negotiated reduction targets, all countries would agree ex ante to impose on themselves an explicit constraint on GHG emissions of the form \( g(\cdot, \theta) \leq k(\theta) \), where \( k(\theta) \) might, for example, be emissions in a given baseline year. Equi-proportional rules are common in international environmental agreements. Such rules provide powerful focal points for discussions as they signal that each signatory country is expected to “pull its own weight” in terms of, say, equal emission reductions as a percentage of status quo levels. Certain equi-proportional rules have emerged from discussions leading to the Framework Convention on Climate Change. One such equi-proportional rule is: developed countries should strive to reduce emissions by 20 percent from a predefined growth path by the year 2000 while developing countries would strive to reach a 20 percent reduction by 2025. Various other emissions limits have been proposed for climate change mitigation (e.g. see Grubler and Nakicenovic 1992). These might take the form of restricting each country to a particular level of GHG emission per capita, or per unit of GNP. In the former case, for example, this would amount to appending to the first-best or to the noncooperative solution constraints of the following form:

\[
\frac{g(\bar{X}(\theta), \bar{Y}(\theta), \theta)}{N(\theta)} \leq \gamma \left( \frac{I(\theta)}{N(\theta)} \right)
\]

2. The application of various equity concepts to global climate change are reviewed by: Barrett 1992; Grubb, et al. 1992; Rose 1992; and Young and Wolf 1992.
where $\psi(\cdot)$ is a nondecreasing function of per capita income $I(\theta)/N(\theta)$. We will consider the impact of such a constraint using the simulation framework below.

Because of the difficulty of measuring GHG outputs, this constraint might be imposed on inputs, or on outputs in particular sectors (e.g., electric power). Alternatively, countries might choose to impose taxes on GHG emitting consumption, with the proceeds of these taxes being directed towards investment in mitigating the effects of GHG. Taxes on consumption could take the form:

$$x(\theta) \geq \tau(\theta)I(\theta), \theta \in \Theta. \tag{9}$$

where the tax rate $\tau(\theta)$ could be an increasing function of per capita income levels $I(\theta)/N(\theta)$. If $\tau(\theta) = 0$ for some countries, then the effect would be to impose targeted taxes only on certain countries (those for which $\tau(\theta) > 0$). Again, these constraints would reduce aggregate unconstrained welfare, assuming cooperation, but might be required to assure cooperation.

**Solutions with No Transfer Payments**

**Benchmark Noncooperative Outcome**

The noncooperative solution developed above provides the benchmark against which all other solutions will be compared. In the benchmark case, each country group allocates GNP to consumption and investments in GHG reduction to maximize expected welfare with no transfers of resources between countries. The noncooperative outcome from the simulation framework is shown in Annex Table 3–A1. The allocation of GNP to consumption, $y(\theta)$, and GHG reduction, $x(\theta)$, for each country group is imputed by our model using assumptions for (5)–(7) stated above. In this benchmark noncooperative case, only the high-income (OECD) economies (along with some transition economies) invest in mitigation of industrial CO$_2$ emissions.$^3$ $IC_x(\theta)$ is the incremental cost of investments to reduce industrial CO$_2$ emissions as depicted in Figure 3–2, above.$^4$ In this setting, it appears that low cost opportunities for GHG abatement exist in developing countries.

**Negotiated Target of 30 percent Reductions from 1989 Emissions: Across-the-Board**

We now impose a constraint on the benchmark case that models a pledge to reduce emissions equi-proportionally: every country group pledges to reduce emissions by 30 percent from 1989 baseline levels. Key implications are displayed in Figure 3–3, which shows the expected welfare of each country group under this pledge relative to the noncooperative benchmark (detailed results are shown in Annex Table 3–A1). High-middle income developing countries and OECD countries would find adhering to such a commitment unpalatable—domestic investments they must make to meet this commitment are greater than the benefits of reduced GHG emission, and this would reduce their net welfare. Without the ability to claim credit for financing GHG reduction in other countries, the incremental cost of achieving 30 percent reductions rises to prohibitive levels in both country groups (see Figure 3–2). If our assumed cost curves even remotely reflect actual conditions, commitments made to meet such a target must be seen as noncredible.

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3. Country groups that spend nothing on GHG mitigation in the benchmark scenario obtain more marginal value from consumption than from investment in GHG mitigation. This result is entirely an artifact of our assumptions within the illustrative simulation framework.

$$ICx(\theta)=\frac{\partial x(\theta)}{\partial g(\theta)}=\frac{-(\delta+x)^2}{\delta(\alpha-\beta)y}.$$
Negotiated Target of 30 percent Reductions from 1989 Emissions: Equal Per Capita Emission Rights

Another equity principle that has been put forward in climate change discussions is the concept of equal emission rights per capita. Using the country groups of our simulation framework, a cap on CO$_2$ emissions of 7 tons per capita per year would achieve a 30 percent reduction from G(X,Y)$_{1989}$. At this level, global allowances would be well above 1989 emissions, but many country groups would not use their entire quota. The constraint would not be binding on poor countries, but would be tightly binding on OECD countries where 1989 emissions averaged about 12 tons/capita. The expected welfare of each country group relative to the noncooperative benchmark is shown in Figure 3-3. To meet this constraint without the ability to trade in obligations or rights, OECD countries would need to increase GHG abatement spending substantially and pursue very expensive projects while relatively low cost opportunities remain in developing countries (see details in Annex Table 3-A1). According to our illustrative framework, a strict application of this principle would not be acceptable to industrial countries, but there would be substantial gains to trade in emission rights.

Solutions with Transfer Payments

Now, we examine the implications of cooperation between country groups in the form of resource transfers between country groups. In these cases, country groups maximize expected welfare by allocating resources to consumption, investments in domestic GHG reductions, and to investments in foreign GHG reductions. We assume at this stage of the analysis that international transfers, s(θ), are optimally allocated to achieve the biggest "bang-for-buck." Moreover, we assume that: (a) perfect information exists on all investment opportunities for GHG reduction; (b) transaction costs for identifying and financing GHG reduction investments are negligible; and (c) all opportunities are made available for financing at incremental cost.

Cooperative Reallocation of GHG Investments (without strategic adjustment)

In this case, countries efficiently reallocate among themselves the total pool of funds committed by individual countries for GHG investments in the benchmark noncooperative outcome, X$_0$. However, in anticipation of such reallocations, countries are assumed not to strategically adjust their consumption and investment decisions. The problem may be expressed in the form:

\[
\text{Minimize } G(X,Y) = \sum_{\theta \in \Theta} g(x(\theta), y(\theta); \theta) \tag{10}
\]

such that

\[
\sum_{\theta \in \Theta} x(\theta) \leq \sum_{\theta \in \Theta} \bar{x}(\theta) \tag{11}
\]

which at optimum equates the marginal product of GHG investment $g_X(\theta)$ across countries.

Results from our simulation framework are labeled "first step" in Figure 3-4. Expected utility for every country group from this "first step" cooperative outcome is higher than in the benchmark noncooperative outcome—all country groups would be better off than in a noncooperative world. Roughly 40 percent of OECD investments that would have chased high cost domestic projects in a noncooperative world would instead finance bigger "bang-for-buck" projects in developing countries (see details in Annex Table 3-A1). This efficient reallocation of global GHG abatement investments, X$_0$, would serve to reduce global industrial CO$_2$ emissions, G(X,Y), by roughly the same levels as the negotiated reduction targets without transfer payments.
modeled above. Global cooperation in this way presents an opportunity for all countries to emerge winners—the developed countries through winning the cooperation of developing nations and access to high-payoff projects in these countries, and the developing countries through additional resources received for investment.

Cooperative Reallocation of GHG Investments (with strategic adjustment)

The preceding cooperative solution assumes that countries will not strategically readjust their committed levels of domestic investment and consumption in anticipation of international transfers. This is likely to be difficult to avoid in practice. However, outcomes obtained when strategic readjustment is accounted for still dominate the noncooperative solution.

We characterize cooperative reallocation with strategic adjustment in a "sophisticated response" scenario in our simulation framework. Here, all country groups are allowed to reallocate resources domestically to maximize expected welfare, given the vector of resource transfers determined in the "first step" cooperative solution and subject to the constraint that positive transfers from the global coalition can be used only for investments in GHG reduction. Under these conditions, investments that would have been made in GHG reduction in a noncooperative world by all non-OECD country groups would be entirely displaced by international resource transfers. Conversely, OECD countries would find it in their interest to increase domestic abatement investments substantially. This increased OECD investment would reduce global CO\textsubscript{2} emissions further and, thereby, result in welfare gains for all countries as shown in Figure 3-4 "sophisticated response" (details in Annex Table 3-A1).

Cooperative Reallocation to Maximize OECD Welfare (with strategic adjustment)

Assuming that OECD countries will emerge as the exclusive financiers of global GHG reductions, it is natural to ask what level of transfers might be expected if the OECD were to maximize its own expected welfare by investing in GHG reductions in all country groups. As before, we assume that transfers from the OECD could only be used for investments in GHG reduction. Under these assumptions, our simulation framework shows that the OECD would increase its total resources devoted to domestic GHG abatement and transfers, relative to the previous outcome. The resulting investments would serve to reduce global GHG emissions even further and, thereby, make all country groups better off (see Figure 3-4 "OECD's best").

Summary

We have shown, both analytically and through a simulation framework, that cooperation in financing projects to reduce GHG emissions dominates noncooperation. Compare the cooperative solutions in Figure 3-4 with the commitments in a noncooperative world modeled in Figure 3-3. Each cooperative scenario would achieve roughly the level of global GHG reductions that the commitments of Figure 3-3 aim to achieve, but each cooperative scenario is feasible since every country group is better off than in a noncooperative world.

The scenarios evaluated above do not, of course, exhaust the kinds of commitments that are possible and may be necessary to ensure cooperation. From a policy perspective, it is important to examine how well various institutional arrangements may perform in enhancing cooperation. For each proposed institutional arrangement, the key issues to be evaluated are: (a) information imperfections and asymmetries that imply transactions costs in identifying and financing GHG reduction investments; (b) transac-
tions costs of monitoring and enforcing commitments; and (c) the incentive structure determined by how the global surplus is to be shared between financiers and suppliers of GHG reduction projects. We examine these issues next in the next section.

**Institutional Mechanisms for Implementing Global Collaboration**

The analysis and simulation results provided in the previous sections clearly demonstrated the benefits (at both country and global levels) of various cooperative arrangements in GHG mitigation investment. The principles of the Framework Convention on Climate Change are consistent with these results. Each signatory country to the Framework Convention will be obligated to meet certain target limits on GHG emissions, possibly with the financial assistance from the global community. In the foregoing discussion we assumed the existence of an institutional mechanism to effect the international resource transfers necessary to achieve the desired benefits of cooperation. In this section, we examine alternative institutional designs to implement these actions based on criteria developed below.5

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5. It should be noted that we are not exploring intracountry implementation issues here. Decentralization at the national level has been extensively analyzed and various schemes, most notably tradable permits and taxes, have been developed to achieve target reductions in GHGs in various sectors efficiently. These alternative approaches themselves have yet to be examined fully in an empirical setting, and it seems likely that no single scheme will be optimal for every country (see Wheeler 1992). Thus, decentralization at the national level should be understood in terms of both differing sectoral targets for GHG mitigation, but also differing effectiveness of alternative policy instruments in achieving these sectoral targets in different countries. Thus, the key issue is that each country commits itself to a well-intentioned effort to achieve fair targets for GHG reduction. How they achieve this will be country specific, although sharing

We focus at the outset on two polar extremes in the possible set of institutional mechanisms: (1) pure multilateral schemes such as the Global Environmental Fund (GEF); and (2) pure bilateral schemes such as the joint implementation programs currently being proposed by the United States and some other countries that plan to finance GHG reduction investments in developing countries. Multilateral schemes are characterized by a central pool of funds contributed by the investing countries which is then disbursed to recipient countries based on specific criteria, such as the incremental costs of the projects funded. Donor countries are not able to identify themselves with individual projects, which places a heavy burden of project monitoring on the central agency. In bilateral schemes, on the other hand, the terms of financing can be agreed on by the two sides, and the country putting up the financing can monitor the progress of the projects. In such a bilateral approach, countries making cross-border investments may obtain credit or offsets against their own obligations under the Framework Convention. The benefit accruing to the financing countries, which is the avoided cost differential between the cost of domestic and cross-border investment, is very visible, which makes it politically tenable to put up the financing from public funds. These alternative schemes are illustrated in Figure 3–5. After assessing the advantages and disadvantages of these schemes at some length, we consider the potential for hybrid approaches which combine the better features of multilateral and bilateral schemes. We consider the following criteria in our assessment:

- Price per unit of GHG reduced and total cost to investing countries

of best practices and new technologies across countries should be facilitated (see below).
• Incentives for project nomination and efficient implementation

• Monitoring and informational efficiency

• Transactions costs

Cost to Investing Countries

The discussion in the previous section has proceeded on the assumption that the global community would have complete control in making investments in GHG mitigation projects without regard to issues of national sovereignty. The reality, of course, is that each country would be responsible for meeting the reduction targets it has committed to in the Framework Convention, and countries seeking to make cross-border investments would have to do so with the acquiescence of the recipient country.

A key issue that arises in this context relates to the basis on which transfer payments are made to recipient countries for the "purchase" of GHG mitigation. In the past, most notably in the case of the Montreal Protocol implementation, the basis for payment has been the incremental cost borne by the country of implementing the project. This approach has been criticized for being administratively cumbersome and providing few incentives (if any) for project acceleration by the recipient countries (see Allen et al. 1992; Munasinghe and King 1991). Recent anecdotal evidence especially pertaining to the slow pace at which funds have been disbursed for the mitigation of Ozone depleting substances seems to confirm this view.

The simulations in the section, Modeling International Cooperation for Efficient GHG Mitigation Investments, assumed that all projects are financed at their incremental costs, which implies that no surplus accrues to the recipient countries from this financing. Assuming recipient countries agree, this gives the biggest "bang-for-buck" for the investment. If recipient countries are firmly committed to a schedule of investments which is not conditional on the availability of external financing, such an approach may be somewhat realistic, taking account also of the monopsonistic nature of the centralized multilateral institution. On the other hand, if the pace and size of GHG mitigation investment in recipient countries is dependent upon the scale of external financing, which seems to be a plausible scenario especially in the case of larger countries such as India and China, we would argue that payments in excess of incremental costs would be required for effective and speedy implementation of GHG mitigation projects.

Such an outcome is likely in a bilateral scheme where investor countries may be thought of as "competing" for low-cost GHG mitigation projects especially in the developing world. The likely result of such competition is that investor countries would be willing to pay recipient countries somewhat more than incremental costs to secure offsets through their investment in low-cost projects. In an extreme case, a single global "market-clearing" price which equals the incremental cost of the last project undertaken will be paid by investor countries for their cross-border GHG mitigation investments. The basic idea underlying this discussion is illustrated in Figure 3-6.

Note that the single market price is similar to the price that would result from a market in emission permits, either at the global level or, as presently exists, at the national level.

Using the simulation framework, we have estimated the costs that would be incurred in the two polar cases we have been examining in this section: (a) all cross-border investments financed at incremental cost (all surplus accrues to the financing countries); and (b) all cross-border investments financed at a single "market clearing" price (all surplus to host countries). These esti-
mates are presented in Table 3-1 for two scenarios with transfer payments.

These simulation results illustrate the implications of alternative institutional mechanisms. Financing projects under a single market clearing price would result in a lower level of international transfers purchasing fewer GHG reductions than if projects were financed at incremental cost. International transfers would be relatively less cost effective under a market scheme since a large share of the transfers would be “incentive payment” in excess of project costs. Both simulation scenarios in Table 3-1 show that more than half of the international transfers would be surplus or “incentive.”

**Incentive Implications**

As noted above, the payment mechanism associated with the institutional scheme has a direct impact on the incentives for participation and active cooperation by the recipient countries. Buying GHG reductions at their incremental costs, may be least-cost from the standpoint of the investing countries. However, as pointed out for the analogous case of ozone layer protection in Munsinghe and King (1992), such an arrangement provides no financial surplus to the recipient countries—which is likely to have an adverse effect on their incentives to cooperate by nominating and implementing projects speedily. This may be a less significant factor if the recipient countries are obligated by the Framework Convention to undertake these projects anyway, with or without external financing. However, it is unlikely that the cooperation of many developing countries can be obtained without such financing, and the experience to date shows that this may need to be in excess of the costs that they incur—to provide an additional incentive.

Surplus payments in excess of costs may be viewed as “lubricants for cooperation.” Since these surplus payments are likely to be highest for the lowest-cost (biggest “bang-for-buck”) projects, they create strong incentives for recipient countries to locate and nominate these projects for financing. They also create incentives for accelerated implementation of big “bang-for-buck” projects, which is very desirable from the standpoint of the objectives of the Framework Convention.

Also as we have noted above, surplus payments are almost inevitable in bilateral schemes if investing countries compete globally for the cheapest projects. However, taking account of the relative strengths and weaknesses of the parties to these bilateral schemes, the considerable barriers to information flow, and the obligations imposed on the parties to the Framework Convention, it is very unlikely that prices will increase all the way to levels associated with full competition for mitigation projects.

Surplus payments may be very desirable in multilateral schemes also, to overcome the incentive problems that were discussed above. One approach to enhance incentives would be to conduct what amounts to a global auction (see Allen et al. 1992) which is effected by announcing a fixed price (in $/ton) which the multilateral institution would pay for mitigation projects. The effect of such a price offer is to attract all projects that have unit costs of GHG mitigation that are below the offered price, which will be the best projects available globally. Over time, the bid price can be increased progressively to attract higher cost projects, up to the desired aggregate level of GHG mitigation.

Figure 3-7 illustrates the impact of payments (bilaterally or multilaterally) in excess of the cost of the projects.

**Monitoring and Informational Efficiency**

In order for a scheme of cross-border investments to work, the following criteria must be met regardless of the institutional
3. Financing Global Environmental Programs: Cooperation and Institutional Design

mechanism that is adopted for implementing the scheme of resource transfers:

1. The investing countries should be able to monitor the investments/measure emissions and whether or not the desired results have been achieved;

2. The investing countries should be able to impose (at least moral if not financial) sanctions on noncompliant countries.

A third desirable characteristic of efficient decentralized implementation is that the shadow price of GHG reduction in each country and sector be estimable so that a rough efficiency benchmark (viz., equalized incremental abatement costs) is evident to all participating countries. Using market mechanisms at the national level could enhance significantly the estimation of incremental abatement costs in each country. For example, in the electric power sector if an efficiently functioning emissions trading market were present, the market price for an emissions permit for GHGs would represent the cost of a unit reduction in GHGs in that sector. The challenge is to link sectors such as electric power, which are more easily monitored and controlled, with other sectors, such as agriculture and manufacturing, where the total GHG emissions and the cost of reducing these will be considerably more difficult to estimate on an ongoing basis. In these sectors, from both a national as well as a global perspective, it seems likely that a variety of country-specific instruments and projects will be required to achieve efficient GHG mitigation in the implementation of Country Plans.

From the standpoint of monitoring and enforcement pertaining to specific projects, there appears to be no obvious advantage to one or other of the two mechanisms we have been considering here. Where it is possible to leverage off existing trade/investment/aid links between two countries, monitoring in a bilateral scheme could be very effectively handled. A multilateral agency, on the other hand, would have the benefit of some scale economies especially in the use of specialized expertise.

From the standpoint of gathering and disseminating information across countries, on the other hand, a centralized multilateral agency is at a clear advantage. Thus, even with bilateral investment flows, such a multilateral agency established and funded by the investing countries could perform a very valuable role in promoting cooperative activity by each signatory country, including sharing of best practices, publishing information on potential investments and their costs, highlighting priority areas and providing technical assistance.

Transactions Costs

The transactions costs of project selection, implementation and monitoring are clearly an important consideration in institutional design for GHG mitigation investment. Because of issues of national sovereignty and physical separation between investing and host countries, it is clear at the outset that the magnitude of transactions costs associated with specific projects will depend on the stance taken by the host country institutions towards these projects. Thus, for example, much of the work associated with the project could occur at the local or project level if the host countries were to take an active interest in the project, which would depend in part on their stake in the project. It is clear also that the transactions costs associated with project identification, financing and monitoring are likely to be very much a function of the size and complexity of the project, and also the role and competence of its local partners. If the incentives for local participation can be correctly structured to be consistent with the overall objectives of the project, this would greatly reduce monitoring needs and associated costs.
The level of transactions costs would also depend upon existing institutions. Many industrial countries have existing agencies for the purpose of channeling foreign aid on a bilateral basis, which could also be used for the purpose of channeling these investments. On the other hand, there is a long tradition of channeling development aid through multilateral institutions such as the World Bank. Hence, from the standpoint of transactions costs, the success of a new scheme of financing GHG mitigation projects would depend upon the extent to which existing institutional resources can be utilized.

Hybrid Approaches

It is clear from the foregoing that multilateral and bilateral schemes have their relative advantages and disadvantages. We summarize these below in Table 3-2 according to the criteria that we used above.

Multilateral approaches are informationally more efficient, since all available information can be centrally aggregated and then disseminated as available. On the other hand, paying out only incremental costs, as is currently the practice of the GEF, greatly reduces the incentives for host countries to take a proactive role in nominating and implementing projects. In the longer term, the cost of this may be considerably higher than the immediate savings in disbursements to the host countries.

In Figure 3-8, we propose an alternative hybrid arrangement where a centralized multilateral institution (e.g. a Global Environmental Coordinator) would undertake information transfers, assisting in project identification and technical assistance, and possibly keeping a scorecard of environmental investments and setoffs by individual countries. Investments themselves can be undertaken bilaterally, or directed through multilateral funds such as the GEF, depending upon the preferences of the countries concerned. In the latter case, our analysis would suggest the use of an auction type surplus sharing mechanism rather than merely compensating incremental costs.

Conclusions and Directions for Future Research

This chapter addresses several issues related to global cooperation and international resource transfer for reducing GHG emissions to mitigate global climate change, currently an area of significant academic and policy interest. Global environmental projects are quite unique because their benefits are shared globally, whereas investments have to be undertaken by the countries in which the projects are located. We develop an economic framework built around a group of countries or country groups with heterogeneous preferences and incomes to evaluate opportunities for efficiency gains through international resource transfers and to assess alternative institutional mechanisms for effecting these transfers. To illustrate this framework, we identify its parameters for 1989 data and use it to simulate the outcomes associated with various levels of international cooperation and resource transfers.

Our analysis clearly demonstrates that because of differences in project marginal benefits and country preferences, cross-border investments (e.g. by OECD countries in GHG abatement projects located in developing countries) can create significant win-win situations from the standpoint of all countries—i.e. those who fund and those who host investments—relative to more autarkic outcomes where all such investments are carried out by the individual countries concerned. Thus, rather than seeing a tradeoff between equity and efficiency, as is sometimes argued in the economics literature, we argue that, in the present context, these two welfare criteria are mutually reinforcing. The focus of transfers is clearly to promote efficiency through tar-
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gated project funding. But the process of identifying, implementing and monitoring optimal project funding opportunities requires cooperation from the countries in which projects are located. Obtaining this cooperation, together with a commitment to GHG mitigation targets and funding procedures, will require a sense of perceived fairness or equity in the burdens and benefits associated with these targets and procedures. Absent this sense of equity, only a range of noncooperative outcomes become possible for the global coalition. To the extent that such noncooperative outcomes entail efficiency losses, maintaining a sense of perceived equity is efficiency enhancing.

The success of a global environmental investment program depends critically on the institutional mechanism that is employed for implementing it. We compare and contrast multilateral (e.g. through a Global Environmental Fund) and bilateral (i.e. joint implementation) schemes. A critical feature that differentiates these schemes is the allocation of the surplus associated with individual investments between the investing countries (and by extension the global community) and the host country. The global environmental fund as it is currently constituted pays out incremental costs to the host countries, thereby capturing the entire project surplus for the global community. As is evident from the recent track record of the GEF, this dampens incentives for project selection and their speedy implementation, while also increasing the transactions costs expended by the global community. We examine more decentralized and market-oriented approaches, both bilateral and multilateral, which through the allocation of part of the surplus to host countries, have the potential to resolve these problems and considerably speed up the implementation of global environmental projects.

The key focus of this chapter has been on the benefits of cooperation in an effort to mitigate global climate change. As our results have demonstrated, there appear to be several cooperative outcomes which are more efficient in terms of GHG reduction and welfare improving for all countries, relative to the business-as-usual noncooperative outcome. It is important that the global community strive for these outcomes.

Capturing the fruits of cooperation is contingent upon the development of effective institutional arrangements to transfer resources between countries. Given the nature of the investments (not so much the technology itself but the overlay of issues related to the externalities associated with the investments, national sovereignty and spatial dispersion), it is very important to have as many actions as possible undertaken by the host countries themselves in a way that is consistent with the objectives of the investing countries. As we have noted, this can be accomplished by a more equitable sharing of benefits between host and investing countries. The global environment facility as it is currently constituted pays out incremental costs to the host countries, thereby capturing the entire project surplus for the global community. As is evident from the recent track record of the GEF, this dampens incentives for project selection and their speedy implementation, while also increasing the transactions costs expended by the global community. We examine more decentralized and market-oriented approaches, both bilateral and multilateral, which through the allocation of part of the surplus to host countries, have the potential to resolve these problems and considerably speed up the implementation of global environmental projects.

Fruitful areas for further research on the institutional design question seem to be the following:

• The analysis of effective policy implementation approaches and incentives to promote efficient (win-win) conservation
measures which conserve GHG-rich resources.

• A targeted analysis of the energy sector with both conservation and efficiency in mind, including coordinating energy and environmental concerns with resource options, regulatory policy, privatization initiatives and other economic instruments.

• Assessment of the performance of decentralized instruments such as tradable emission rights, monitoring, regulated competitive structures, and incentive regulation. The assessment should couple both theory and empirical assessment, including simulation, experimental assessments and field studies.

• Empirical and theoretical research on the efficiency properties of alternative global institutional designs which meet the prima facie requirements of equity laid out in this chapter. On both the theoretical and empirical sides, this could begin with a more detailed study of the efficiency consequences of various imposed equity constraints as discussed in the sections Modeling International Cooperation for Efficient GHG Mitigation Investments, and Institutional Mechanisms for Implementing Global Collaboration.
Annex 3–1
Details of the Basic Economic Model

In the section, Modeling International Cooperation for Efficient GHG Mitigation Investments, we summarize the impacts of alternate levels of cooperation (as manifested by resource transfers and schemes of burden sharing) on the efficiency of GHG mitigating investments. This summary is based on the conceptual economic framework which is presented in detail here.

The Basic Economic Model

We begin by developing in this section a two-stage model of global interactions associated with reducing GHG emissions. Each country faces a number of trade-offs in confronting the issues of global climate change. The essential features of the model are as follows. First, we reflect the consequences of global GHG emissions and the uncertainty of global climate change on each country. These effects may be quite different from one country to the next. Second, we reflect the cost of investments in technologies or activities directed toward reducing GHG emissions by the country. Resources used for this purpose could clearly be devoted to other productive purposes in the country and the economic consequences of diverting their use to reducing GHG emissions is reflected in the model as a reduction in current consumption.

Let the “GHG production function” for country θ, \( g(x(\theta),y(\theta);\theta) \), denote the total GHGs (measured in units of global climate change potential) generated by country θ in stage 1, and let the total GHGs generated in all countries be denoted by \( G(X,Y) \) so that

\[
G(X,Y) = \sum_{\theta \in \Theta} g(x(\theta),y(\theta);\theta) \quad (A1)
\]

where \( \Theta \) is the country index and the set of all countries is denoted \( \Theta \), \( x(\theta) \) is investment by country \( \theta \) to reduce GHG emissions at stage 1, \( y(\theta) \) is consumption by country \( \theta \) at stage 1, \( X \) is the vector of all country investments \( \{x(\theta) \mid \theta \in \Theta\} \), and \( Y \) is the vector of all country consumptions \( \{y(\theta) \mid \theta \in \Theta\} \). We assume throughout that, for each \( \theta \), \( g(x,y,\theta) \) is increasing in consumption and decreasing in mitigation investments, i.e., \( g_x < 0, g_y > 0 \). We also assume that \( g(.,\theta) \) is jointly convex in \((x,y)\), so that investments, \( x \), have a declining marginal impact on (reducing) \( G \) and consumption has an increasing marginal impact on \( G \).

We assume the following aggregate welfare function, denoted \( U(\theta) \), for country \( \theta \):

\[
U(X,Y,\omega;\theta) = V(G(X,Y),y(\theta),\omega;\theta), \theta \in \Theta \quad (A2)
\]

where \( \omega \in \mathbb{R}^+ \) is an uncertain state of the world and \( U \) depends on \( X \) only through aggregate GHG emissions \( G \). We will assume that \( V \) is decreasing in \( G \), increasing in \( y \) and jointly concave in \( G \) and \( y \). Given these assumed properties of \( G \) and \( V \), it is straightforward to show that, for each \( \omega \) and \( \theta \), \( V \) is concave in \((X,Y)\), from which it follows that, for each \( \theta \in \Theta \), the expected value of \( V \) over \( \omega \) is concave in \((X,Y)\).

We will also be interested in characterizing the Pareto-efficient outcomes to the collective consumption-investment problem associated with the above country welfare functions \( U(\theta) \). The set of Pareto (or first-best) outcomes is important both as an efficiency benchmark as well as in understanding various “cooperative” solutions, described more fully below, to the global problem of GHG mitigation.
For this purpose, we will define a (weighted utilitarian) global welfare function $W$ as

$$W(X, Y) = E_{\omega}\left\{ \sum_{\theta \in \Theta} \eta(\theta)U(X, Y, \omega; \theta) \right\}$$  \hspace{1cm} (A3)

where $F(\omega)$ is the probability distribution on the states of the world, $E_{\omega}$ is the expectation at stage 1 with respect to the distribution $F(\omega)$, and $\eta(\theta)$ satisfy:

$$\eta(\theta) \geq 0; \quad \sum_{\theta \in \Theta} \eta(\theta) = 1.$$  \hspace{1cm} (A4)

Since, as noted, the expected utility functions $E\{U(\cdot; \omega)\}$ are concave, the Pareto set of allocations from any convex feasible set are given by the argmax $W_{\eta}$ as the weights $\{\eta(\theta) | \theta \in \Theta\}$ vary over the feasible set defined by (A4).  

$U$ may be thought of as the net economic benefits realized from the country's activities in stages 1 and 2. We assume that investments $x(\theta)$ in GHG reduction and consumption $y(\theta)$ are related by the following budget constraint:

$$I(\theta) = x(\theta) + y(\theta) - s(\theta)$$  \hspace{1cm} (A5)

where $I(\theta)$ is income for country $\theta$ in stage 1, $s(\theta)$ is a monetary transfer payment to country $\theta$ at stage 1, and $S = \{s(\theta) | \theta \in \Theta\}$ is the vector of all ex ante transfers.

Thus, investments in GHG reduction will necessarily reduce consumption $y(\theta)$ unless offset by transfers $s(\theta) > 0$ to $\theta$ from other countries. For feasibility, we require the following restrictions on transfers among countries:

$$\sum_{\theta \in \Theta} s(\theta) = 0.$$  \hspace{1cm} (A6)

### The Benchmark

#### Noncooperative Outcome

As noted above, we develop here the benchmark noncooperative outcome based on uncoordinated actions by individual countries. To characterize this noncooperative solution, we use the Nash equilibrium concept for the associated game in which each country attempts to maximize (A2) subject to (A5), with $s(\theta) = 0$. The problem in this case for country $\theta$ will be:

$$\text{Maximize } E_{\omega}\{V(G(X, Y, \omega; \theta))\}$$  \hspace{1cm} (A7)

subject to:

$$I(\theta) = x(\theta) + y(\theta)$$  \hspace{1cm} (A8)

Substituting (A8) into (A7), country $\theta$ is assumed to solve the following problem, taking other country decisions as given:

$$\text{Maximize } E_{\omega}\{V(G(X, I - X, I(\theta) - x(\theta)), \omega; \theta))\}$$  \hspace{1cm} (A9)

subject to:

$$I(\theta) > 0.$$  

7. Because income can always be productively invested in reducing GHGs, with strict improvements in welfare resulting therefrom, it is clear that the budget constraint (A5) will hold as an equality at optimum.

---

6. Note that the traditional approach to defining the Pareto set is to set individual country reservation expected utility levels for all but one country and then maximize the remaining country's expected utility over feasible allocation vectors $(X, Y)$ and compensation vectors $S$ and $T$ (if compensation is allowed). As these reservation utility levels are varied, the Pareto set is generated. The present approach, using the weighted welfare function (A3), is more congenial to the analysis, but it is entirely equivalent, where the weight $\eta(\theta)$ corresponds to the dual variable associated with country $\theta$'s reservation utility level in the traditional approach. The reader will also note that many of these cooperative solutions will be unacceptable from the standpoint of the stated objectives of global cooperation, i.e. to minimize GHG emissions, since they also reallocate resources for consumption. However, this general formulation is convenient for characterizing the subset of solutions that will meet all necessary criteria, and we will examine specific cases of interest later.
Thus, the following first-order conditions characterize the Nash noncooperative equilibrium:

$$x(\theta) \frac{\partial EV(\theta)}{\partial x(\theta)} = 0;$$

$$\frac{\partial EV(\theta)}{\partial x(\theta)} = E_\omega \left\{ \left[ g_x(\theta) - g_y(\theta) \right] V_{x(\theta)} + V_{y(\theta)} \right\} \leq 0; \quad \forall \theta \in \Theta$$

(A10)

### A First-Best Framework for Characterizing Cooperative Outcomes

By a first-best solution, we mean a Pareto allocation \((X, Y, S)\) for the above country welfare functions and constraints, i.e. a solution which cannot be improved upon for all countries simultaneously. From the above, the Pareto solutions \((X, Y)\) must be solutions to the following problem for some feasible weighting vector \(\{\eta(\theta) | \theta \in \Theta\}\):

$$\text{Maximize } E_\omega \left\{ \sum_{\theta \in \Theta} \eta(\theta) V(G(X, Y, \gamma(\theta), \omega; \theta)) \right\}$$

subject to (A5)–(A6), where \(E_\omega\) is the expectation at stage 1 with respect to the distribution \(F(\omega)\). Thus, the first-best solution is effected by putting all resources in the hands of a central global authority, which is assumed to solve (11) with no transactions costs.

Since (A5) holds as an equality at the solution to (A11), we may eliminate \(y(\theta)\) by substituting (A5) into (A11). The resulting problem of interest is then:

$$\text{Maximize } E_\omega \left\{ \sum_{\theta \in \Theta} \eta(\theta) V(G(X, Y, \gamma(\theta), \omega; \theta)) \right\}$$

subject to (A6). From the Lagrangian \(L^C\) for this problem we obtain the following first-order conditions:

$$x(\theta) \frac{\partial L^C}{\partial x(\theta)} = 0;$$

$$\frac{\partial L^C}{\partial x(\theta)} = E_\omega \left\{ \left[ g_x(\theta) - g_y(\theta) \right] \left[ \sum_{\zeta} \eta(\zeta) V_{\zeta}(\zeta) - \eta(\theta) V_{\gamma}(\theta) \right] \right\} \leq 0; \quad \forall \theta \in \Theta$$

(A13)

and

$$\frac{\partial L^C}{\partial S(\theta)} = E_\omega \left\{ g_y(\theta) \sum_{\zeta \in \Theta} \eta(\zeta) V_{\gamma}(\zeta) + \eta(\theta) V_{x(\theta)} \right\} - \mu = 0; \quad \forall \theta \in \Theta$$

(A14)

where \(\mu\) is the dual variable associated with (A6). When \(x(\theta) > 0\), (A13) implies that the change in global benefits associated with transferring a monetary unit from consumption to investment

8. A noncooperative equilibrium exists by the usual arguments.
for GHG reduction in country \( \theta \) must just equal the marginal cost \( E_{w}\{\eta(\theta)V_{\gamma}(\theta)\} \) in lost consumption.

Assuming for the moment that \( x(\theta) > 0 \), we can compare (A10) obtained earlier for the noncooperative case with (A13) above. We see that (A10) implies a similar benefit-cost equality to that discussed above for (A13). In the noncooperative case, however, country \( \theta \) equates the marginal loss in consumption benefits to the benefits for itself of transferring a monetary unit in that country from consumption to investment. By contrast, for Pareto efficiency, marginal consumption losses are equated to global benefits of increased investment in mitigating GHGs.

Comparing the noncooperative solution with the first-best solution, we have shown elsewhere\(^9\) the following:

1. The noncooperative solution is Pareto inefficient in the sense that there are weighting vectors \( \{\eta(\theta) \mid \theta \in \Theta\} \) such that the corresponding cooperative solutions \( (X(\eta), Y(\eta)) \) leave every country better off than under the noncooperative solution.

2. The level of aggregate GHG emissions \( G(X_C, Y_C) \) achieved under any cooperative solution is efficient in the sense that it is the minimum aggregate emission level achievable from total mitigation investments \( \Sigma x^c(\theta) \).

This illustrates how cooperation is key to improving efficiency in GHG mitigation efforts. The first finding indicates that increased cooperation itself can lead to increased efficiency, with respect to both consumption and investment patterns. The second finding notes, in particular, that the most basic level of cooperation could involve simply increasing the efficiency of investments in mitigation activities by focusing on the best alternatives for GHG mitigation investments globally.

---

Table 3-1: Illustrative Costs to Investing Countries under Alternative Institutional Mechanisms

<table>
<thead>
<tr>
<th>Scenario</th>
<th>International transfers ($ billions)</th>
<th>CO₂ reductions due to transfers (tons million)</th>
<th>Incremental cost/ market clearing price ($/ton CO₂)</th>
<th>Surplus ($ billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;First-step&quot; cooperative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ Incremental cost</td>
<td>93.6</td>
<td>6,353</td>
<td>60</td>
<td>288</td>
</tr>
<tr>
<td>@ Market clearing</td>
<td>81.5</td>
<td>4,522</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>OECD’s Best</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ Incremental cost</td>
<td>138.3</td>
<td>6,868</td>
<td>101</td>
<td>555</td>
</tr>
<tr>
<td>@ Market clearing</td>
<td>116.2</td>
<td>4,949</td>
<td>23</td>
<td>67</td>
</tr>
</tbody>
</table>

Source: Illustrative framework results in Table 3-A1.

Table 3-2: Comparison of Multilateral and Bilateral Schemes

<table>
<thead>
<tr>
<th></th>
<th>Multilateral - I</th>
<th>Multilateral - II</th>
<th>Bilateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfers</td>
<td>at incremental cost</td>
<td>at incremental cost plus</td>
<td>at incremental cost plus</td>
</tr>
<tr>
<td>Total transfers required to equalize incremental costs</td>
<td>lowest</td>
<td>higher</td>
<td>highest</td>
</tr>
<tr>
<td>Incentives for accelerated implementation</td>
<td>weak</td>
<td>strong</td>
<td>strong</td>
</tr>
<tr>
<td>Information sharing</td>
<td>efficient</td>
<td>efficient</td>
<td>less efficient</td>
</tr>
<tr>
<td>Monitoring</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Transaction costs</td>
<td>high</td>
<td>lower</td>
<td>lower</td>
</tr>
</tbody>
</table>

Multilateral approaches are informationally more efficient, since all available information can be centrally aggregated and then disseminated as available. On the other hand, paying out only incremental costs, as is currently the practice of the GEF, greatly reduces the incentives for host countries to take a proactive role in nominating and implementing projects. In the longer term, the cost of this may be considerably higher than the immediate savings in disbursements to the host countries.
Annex Table 3–A1: Simulation Framework Details

<table>
<thead>
<tr>
<th>1989 population (millions)</th>
<th>Low Income</th>
<th>India &amp; China</th>
<th>Low-Middle</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989 GNP (US$ billions)</td>
<td>288</td>
<td>673</td>
<td>888</td>
<td>1,012</td>
<td>899</td>
<td>14,804</td>
<td>18,559</td>
</tr>
<tr>
<td>1989 Industrial CO$_2$ (T millions)</td>
<td>367</td>
<td>3,041</td>
<td>1,413</td>
<td>1,163</td>
<td>4,878</td>
<td>9,722</td>
<td>20,584</td>
</tr>
</tbody>
</table>

(θ) average industrial CO$_2$/GNP: 1.27
(θ) lowest industrial CO$_2$/GNP: 0.30
(θ) 1% of GNP: 2.88
(θ) 300,000 - 10*GNP: 297,120
(θ) normalized: 1.00

3.4.1 Benchmark noncooperative solution

<table>
<thead>
<tr>
<th>(θ) (US$ billions)</th>
<th>288.00</th>
<th>673.00</th>
<th>883.00</th>
<th>1,012.00</th>
<th>894.97</th>
<th>14,552.93</th>
<th>18,303.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>x(θ) (US$ billions)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>4.03</td>
<td>251.07</td>
<td>255.10</td>
</tr>
<tr>
<td>g(θ) (T millions)</td>
<td>367.00</td>
<td>3,041.00</td>
<td>1,413.00</td>
<td>1,163.00</td>
<td>4,878.00</td>
<td>9,722.00</td>
<td>20,584.00</td>
</tr>
<tr>
<td>EU(θ)</td>
<td>1,661,995</td>
<td>1,889,116</td>
<td>1,954,517</td>
<td>1,985,294</td>
<td>1,957,351</td>
<td>1,436,036</td>
<td>1,436,036</td>
</tr>
<tr>
<td>IC(θ) (S/T)</td>
<td>10.19</td>
<td>2.36</td>
<td>9.01</td>
<td>27.81</td>
<td>3.11</td>
<td>95.02</td>
<td></td>
</tr>
</tbody>
</table>

3.4.2 Across the board 30 percent cuts from 1989 CO$_2$ emissions (no transfers)

<table>
<thead>
<tr>
<th>(θ) (US$ billions)</th>
<th>286.19</th>
<th>669.86</th>
<th>876.38</th>
<th>954.89</th>
<th>888.11</th>
<th>13,802.44</th>
<th>17,477.86</th>
</tr>
</thead>
<tbody>
<tr>
<td>x(θ) (US$ billions)</td>
<td>1.81</td>
<td>3.14</td>
<td>6.62</td>
<td>57.11</td>
<td>1.081.14</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>g(θ) (T millions)</td>
<td>256.90</td>
<td>2,128.70</td>
<td>989.10</td>
<td>814.10</td>
<td>3,414.60</td>
<td>6,805.40</td>
<td>14,408.80</td>
</tr>
<tr>
<td>EU(θ)</td>
<td>1,666,292</td>
<td>1,893,921</td>
<td>1,958,499</td>
<td>1,974,629</td>
<td>1,960,692</td>
<td>1,434,165</td>
<td>1,434,165</td>
</tr>
<tr>
<td>IC(θ) (S/T)</td>
<td>26.79</td>
<td>5.04</td>
<td>27.19</td>
<td>625.36</td>
<td>7.15</td>
<td>620.99</td>
<td></td>
</tr>
</tbody>
</table>

3.4.3 30 percent Reductions based on equal emission rights per capita (no transfers)

<table>
<thead>
<tr>
<th>(θ) (US$ billions)</th>
<th>288.00</th>
<th>673.00</th>
<th>883.00</th>
<th>1,012.00</th>
<th>883.15</th>
<th>12,530.12</th>
<th>16,269.27</th>
</tr>
</thead>
<tbody>
<tr>
<td>x(θ) (US$ billions)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>15.85</td>
<td>2,273.88</td>
<td>2,289.73</td>
</tr>
<tr>
<td>g(θ) (T millions)</td>
<td>367.00</td>
<td>3,041.00</td>
<td>1,413.00</td>
<td>1,163.00</td>
<td>2,859.28</td>
<td>5,565.52</td>
<td>14,408.80</td>
</tr>
<tr>
<td>EU(θ)</td>
<td>1,666,617</td>
<td>1,895,291</td>
<td>1,960,692</td>
<td>1,991,469</td>
<td>1,959,675</td>
<td>1,419,469</td>
<td></td>
</tr>
<tr>
<td>IC(θ) (S/T)</td>
<td>10.13</td>
<td>2.35</td>
<td>8.96</td>
<td>27.72</td>
<td>11.12</td>
<td>1,486.56</td>
<td></td>
</tr>
</tbody>
</table>

3.5.1 "First step" cooperative solution (allocation of X$_0$ to minimize G(X,Y))

<table>
<thead>
<tr>
<th>(θ) (US$ billions)</th>
<th>288.00</th>
<th>673.00</th>
<th>883.00</th>
<th>1,012.00</th>
<th>894.97</th>
<th>14,552.93</th>
<th>18,303.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>x(θ) (US$ billions)</td>
<td>4.08</td>
<td>27.12</td>
<td>13.85</td>
<td>4.53</td>
<td>48.01</td>
<td>157.51</td>
<td>255.10</td>
</tr>
<tr>
<td>g(θ) (T millions)</td>
<td>202.49</td>
<td>766.37</td>
<td>819.72</td>
<td>1,053.81</td>
<td>1,666.51</td>
<td>10,916.44</td>
<td>15,425.34</td>
</tr>
<tr>
<td>EU(θ)</td>
<td>1,667,153</td>
<td>1,894,274</td>
<td>1,959,675</td>
<td>1,990,453</td>
<td>1,962,509</td>
<td>1,441,194</td>
<td></td>
</tr>
<tr>
<td>IC(θ) (S/T)</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td></td>
</tr>
</tbody>
</table>

EU(θ) - EU(θ)nc (%)

0.31% 0.27% 0.26% 0.26% 0.26% 0.36%
### 3. Financing Global Environmental Programs: Cooperation and Institutional Design

#### 3.5.2 Sophisticated response to transfers (free up own resources for consumption, transfers only for GHG reduction)

<table>
<thead>
<tr>
<th>Low Income</th>
<th>India &amp; China</th>
<th>Low-Mid</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>y(θ) (US$ billions)</td>
<td>288.00</td>
<td>673.00</td>
<td>883.00</td>
<td>1,012.00</td>
<td>899.00</td>
<td>14,461.91</td>
</tr>
<tr>
<td>x(θ) (US$ billions)</td>
<td>4.08</td>
<td>27.12</td>
<td>13.85</td>
<td>4.53</td>
<td>43.98</td>
<td>248.52</td>
</tr>
<tr>
<td>s(θ) (US$ billions)</td>
<td>4.08</td>
<td>27.12</td>
<td>13.85</td>
<td>4.53</td>
<td>43.98</td>
<td>-93.56</td>
</tr>
<tr>
<td>g(*, θ) (T millions)</td>
<td>202.47</td>
<td>766.36</td>
<td>819.74</td>
<td>1,053.79</td>
<td>1,746.61</td>
<td>9,686.09</td>
</tr>
<tr>
<td>EU(*, θ)</td>
<td>1,668,304</td>
<td>1,895,424</td>
<td>1,961,603</td>
<td>1,991,603</td>
<td>1,964,966</td>
<td>14,418.40</td>
</tr>
<tr>
<td>IC, ($/T)</td>
<td>59.98</td>
<td>59.97</td>
<td>59.96</td>
<td>59.98</td>
<td>51.56</td>
<td>101.65</td>
</tr>
<tr>
<td>EU(<em>, θ) - EU(</em>, θ)nc (%)</td>
<td>0.38%</td>
<td>0.33%</td>
<td>0.32%</td>
<td>0.32%</td>
<td>0.39%</td>
<td>0.37%</td>
</tr>
</tbody>
</table>

#### 3.5.3 How well can the OECD do?

<table>
<thead>
<tr>
<th>Low Income</th>
<th>India &amp; China</th>
<th>Low-Mid</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>y(θ) (US$ billions)</td>
<td>288.00</td>
<td>673.00</td>
<td>883.00</td>
<td>1,012.00</td>
<td>899.00</td>
<td>14,552.93</td>
</tr>
<tr>
<td>x(θ) (US$ billions)</td>
<td>0.94</td>
<td>12.10</td>
<td>3.61</td>
<td>0.00</td>
<td>22.68</td>
<td>169.57</td>
</tr>
<tr>
<td>s(θ) (US$ billions)</td>
<td>1.24</td>
<td>32.22</td>
<td>5.05</td>
<td>0.00</td>
<td>42.98</td>
<td>-81.50</td>
</tr>
<tr>
<td>g(*, θ) (T millions)</td>
<td>298.36</td>
<td>1,252.90</td>
<td>1,132.72</td>
<td>1,163.00</td>
<td>2,492.80</td>
<td>10,722.90</td>
</tr>
<tr>
<td>EU(*, θ)</td>
<td>1,665,824</td>
<td>1,901,277</td>
<td>1,958,512</td>
<td>1,988,815</td>
<td>1,968,678</td>
<td>14,440.02</td>
</tr>
<tr>
<td>IC, ($/T)</td>
<td>101.35</td>
<td>101.34</td>
<td>101.31</td>
<td>101.36</td>
<td>101.34</td>
<td>101.33</td>
</tr>
<tr>
<td>EU(<em>, θ) - EU(</em>, θ)nc (%)</td>
<td>0.42%</td>
<td>0.37%</td>
<td>0.35%</td>
<td>0.35%</td>
<td>0.42%</td>
<td>0.38%</td>
</tr>
</tbody>
</table>

4.1.1 "First step" cooperative solution (allocation of X₀ to minimize G(X,Y) under market conditions)

<table>
<thead>
<tr>
<th>Low Income</th>
<th>India &amp; China</th>
<th>Low-Mid</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>y(θ) (US$ billions)</td>
<td>288.74</td>
<td>702.88</td>
<td>886.17</td>
<td>1,012.00</td>
<td>932.20</td>
<td>14,440.02</td>
</tr>
<tr>
<td>x(θ) (US$ billions)</td>
<td>1.48</td>
<td>14.91</td>
<td>5.39</td>
<td>0.00</td>
<td>27.41</td>
<td>247.80</td>
</tr>
<tr>
<td>s(θ) (US$ billions)</td>
<td>2.22</td>
<td>44.80</td>
<td>8.55</td>
<td>0.00</td>
<td>60.61</td>
<td>-116.18</td>
</tr>
<tr>
<td>g(*, θ) (T millions)</td>
<td>272.40</td>
<td>1,132.84</td>
<td>1,048.66</td>
<td>1,163.00</td>
<td>2,296.23</td>
<td>9,678.54</td>
</tr>
<tr>
<td>EU(*, θ)</td>
<td>1,667,749</td>
<td>1,906,849</td>
<td>1,958,512</td>
<td>1,998,815</td>
<td>1,968,678</td>
<td>14,395.57</td>
</tr>
<tr>
<td>IC, ($/T)</td>
<td>18.02</td>
<td>18.02</td>
<td>18.02</td>
<td>28.64</td>
<td>18.02</td>
<td>64.80</td>
</tr>
<tr>
<td>EU(<em>, θ) - EU(</em>, θ)nc (%)</td>
<td>0.23%</td>
<td>0.64%</td>
<td>0.20%</td>
<td>0.18%</td>
<td>0.58%</td>
<td>0.25%</td>
</tr>
</tbody>
</table>

4.1.2 How well can the OECD do (under market conditions)?

Sources: Population and GNP data and country groups: 1991 World Development Report (World Bank 1992); emissions data: World Resources 1992-1993 (WRI 1992). Simulation parameters δ(θ), t(θ), and(θ) are entirely arbitrary. α(θ) has been selected such that emissions in the noncooperative benchmark scenario match actual 1989 emissions.
Figure 3–1: Industrial CO₂ Emissions per Unit Income (kg/$gnp)

Figure 3–2: Industrial CO₂ Reduction Supply Curves ($/ton of reduced CO₂)
Figure 3-3: Relative Expected Utility Resulting from Different Allocation Rules for 30 Percent Overall CO₂ Reductions with No Transfer Payments

Figure 3-4: Relative Expected Utility from Scenarios with Transfer Payments
Figure 3–5: Investment Flows under Multilateral and Bilateral Institutional Schemes

Figure 3–6: Paying for GHG Mitigation Investments
Figure 3-7: The Sharing of Surplus Between Investor and Host Countries

Figure 3-8: Investment and Information Flows in a Hybrid Scheme
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