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***** U N C L A S S I F I E D *****

ROUNDTABLE: IPCC PROGRESS REPORT

Winter Meetings of the Allied Social Sciences Association

Sunday, January 8, 1995 10:15 am

DISCOUNTING CHAPTER

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 turns out to be 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:

- Do nothing (year 0), do nothing (year 50) -- the **ostrich** option
- Do nothing (0), build sea wall if necessary (50). This is the **grasshopper** option: consumption in years 1, ..., 49 is higher than under options c and d; investment is lower at first, but grows as the economy continues to expand.
- Mitigation project (0), do nothing (50). This is **ant** option #1
- Other investment (0), build sea wall if necessary (50). This is **ant** option #2

The stream of benefits is as follows:

Option (yr)	0	...	50	51	52	53	...
a.	0	...	0	0	0	0	...
b.	0		-10	1	1	1	...
c.	-1		1.0	1	1	1	...
d.	-1		11.5	1	1	1	...
			<u>-10</u>				
			=1.5				

Observations

- b (grasshopper) dominates a (ostrich) at plausible discount rates: it is better to build the sea wall if that turns out to be necessary.
- d (ant #2) dominates c (ant #1), as option d leaves \$1.5 million extra after building the sea wall. This can be invested and consumed over a period of years, or consumed immediately.
- 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 (grasshopper) and c (ant #1) will depend on the value attached to the grasshopper's extra consumption in years 0 ... 49, and this will depend on the consumption rate of discount.

Proposal for Mitigation Project

Capital cost, year 0	\$ 1 million
Cost of sea wall, year 50	\$ 10 million
Avolded damages, years 51, 52, 53, ...	\$ 1 milllon/yr
Opportunity cost of capital	5 percent

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)**

Mitigation Project Evaluation: Stream of Benefits

<u>Option (year)</u>	0	...	50	51	52	...
A. nothing, nothing	0		0	0	0	...
B. nothing, sea wall	0		-10	+1	+1	...
C. mitigation	-1		0	+1	+1	...
D. Other Investment	-1		11.5	+1	+1	...
			<u>-10</u>			
			=1.5			

EXECUTIVE OFFICE OF THE PRESIDENT
COUNCIL OF ECONOMIC ADVISERS

Re: IPCC Draft of Summary
for Policymakers (1/20/95)

DATE:

TO: Joe

1/23

FROM: Sally

Summary is too normative:

- 1- preselection of 350-750 ppm for stabilization is ~~not~~ not in background papers
- 2- discounting discussion needs to be clarified
- 3- emission scenarios description is weak and discussion of commitments by countries is misleading
- 4- estimates of damages are in excess of that in the literature
- 5- equity ~~discussion~~ ^{discussion} is vaguely worded

p. 2 par.2

Most of the report is not conducted from the framework of a single global decision maker. Replace beginning with second sentence:

The report identifies a number of general principles and findings that are relevant, no matter what the decision making process, such as those concerning the design of cost effective policies.

p. 2 at B

There is not consensus on the desirable of the use of regulatory instruments.

p. 3 fn. 5 First sentence does not read well. Second sentence may not be correct, because of the "sink" capacity of forests.

p. 4 par. 1 , line 22

"...reflects its objectives, economic conditions, and constraints."
"

The list of considerations that follow mix up conditions that are particular to a given country, and those which are more "universal" such as "international equity."

More generally, the laundry list of possible factors does not seem to say much, and does not reflect any consensus about what are the most salient factors. I suggest deleting remainder of paragraph. (Otherwise, it could be used as an "excuse" for less developed countries not to take any action.)

p. 5 after line 4

Need to add a sentence to the effect that

"Clearly, the dangers of significant harmful effects from global warming increase the greater the degree of concentration of greenhouse gases. The discussion below focuses on the effects associated with concentration levels in the order of magnitude of...."

par 2.

Delete the last sentence (in quotes) and add the following sentence

Studies cited here establish that the pattern of timing of reductions of emissions can have a major effect on the overall costs of mitigation. More paced emission reductions reduce the costs associated with premature retirement of capital and allow taking further advantage of technological improvements that are likely to become available in the future.

par. 3

It is not true that stabilization of atmospheric concentration of greenhouse gases will require

The discussion referring to alternative scenarios will not be of much use to most policymakers, who will not be apprised of the assumptions that underlie them. If one refers to them at all, one should spell out their key assumptions.

p. 6 Since at this point in the report, there is no accepted goal of eventual concentration levels, it would be better simply to describe the thresholds: (a) if the eventual goal is stabilization at the level of.... then emission reductions of this magnitude are likely to be required; (b) if the eventual goal is.... then.....; (c) On the other hand, if the eventual goal is stabilization at a level of or above, then it is likely that no further substantial interventions will be required, at least before.....

p. 6 first full par

I have criticized this par. before. Few economists would subscribe to, let alone know what the report is talking about, when referring to a "safe minimum standard." All of these standards can be embraced in cost benefit analysis, incorporating different degrees of risk aversion. Using this kind of language would significantly interfere with the creditability of the IPCC report in the economics community and beyond, and is likely to be sharply criticized by some governments. This is particularly true, given that the term "dangerous anthropogenic interference..." is nowhere defined. The order of magnitude of anthropogenically induced climate changes is smaller than those which have occurred naturally in the past. While it is true that environmentalists often argue for the absolute standard, and it is sometimes used in establishing health standards, most economists are strongly opposed to these approaches.

Safe minimum uses two terms that few economists would find meaningful: "reduce the risks of climate change to an acceptable level at an acceptable cost."

In the discussion of cost benefit, you should explicitly say that risk considerations can and should be brought into the cost benefit analysis.

If reference is made to the absolute standard and/or safe minimum standard, it must be clearly stated that most economists do not accept these approaches and argue for the use of a cost benefit approach, with appropriate attention paid to the treatment of risk.

par 3

in Figures 3(a) or 3(b), where non-economic effects of climate change are brought into the analysis, but without the development

of a formal way of quantifying the effects and/or valuing those effects relative to the economic impacts.

p. 7 First sentence of first full par. I do not believe that there is a consensus on this conclusion. Better to say

"Because of the large uncertainties...., it is difficult in practice to rely solely on cost benefit analysis for the selection of an appropriate stabilization objective at this time. Still, the information provided by cost benefit analysis is critical in making judgments not only about that decision, but also about the timing of emission reductions and the design of cost effective strategies.

I would delete the last two sentence. The next to the last sentence is somewhat misleading. One can easily extrapolate the benefits and costs associated with different levels of atmospheric concentration (climate change) within a range, at least, based on currently available studies.

p. 7 par. 4 Need to add sentence that estimates of damages for many economies in the temperate and Northern climate zones are small, and in some cases possibly negative.

p. 8 par. 2

no reducible market or government induced imperfections

later "assume market failures or government induced imperfections...

p. 9 first full par.

Discussion would be enhanced by a brief discussion of the most important differences in "input" assumptions.

p. 11

Somewhere in this section one needs to add:

"Issues of equity and efficiency can, however, for the most part be separated. Cost effective strategies can be developed embracing a variety of ways for sharing the burden. Efficiency will require full participation of the developing countries, including some forms of commitments for emission reductions."

Minor comments

p. 4 par. 3.

"relatively costly. However..."

p. 4, par 4

"...emissions. Hence..."

**INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE**

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MEMORANDUM

TO: James Bruce
Hoesung Lee
Richard Odingo
Lorents Lorentsen
Bert Bolin
Sally Kane
Narasimhan Sundararaman

FROM: Erik Haites 

RE: Attachment

DATE: January 20, 1995

Please review the revised draft of the Summary for Policymakers and send me your comments by Monday, January 23.

Thank you.

JANUARY 20 DRAFT. DO NOT QUOTE. FOR REVIEW ONLY**SUMMARY FOR POLICYMAKERS
SECOND ASSESSMENT REPORT, WORKING GROUP III****The Context**

This assessment of the socio-economic literature related to climate change has been undertaken in the context of sustainable development as reflected in the Framework Convention on Climate Change. This Convention is now a key element in the decision making framework on climate change (Chapter 2).

The ultimate objective of the Convention is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."¹

The Convention specifies that to achieve this objective the "Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures should be cost-effective ..."²

Each of the Annex I Parties is committed to "adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs."³

¹ *United Nations Framework Convention on Climate Change*, Article 2. The Intergovernmental Negotiation Committee (INC) requested that the IPCC assess the scientific evidence that might help policy makers interpret Article 2 of the Convention. This topic will be addressed in the IPCC's Second Assessment Report to be published in 1995.

² *United Nations Framework Convention on Climate Change*, Article 3.3.

³ *United Nations Framework Convention on Climate Change*, Article 4.2(a).

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1 The Convention thus implies, and the literature assessed in this report (Chapters 1, 2,
2 8 and 9) supports a strategy of "act - then learn - then act" where the actions to
3 address climate change are periodically adjusted in light of new knowledge and
4 developments. The ultimate objective of stabilizing atmospheric concentrations of
5 greenhouse gases, although not yet operationally defined, provides guidance for
6 policymakers when considering initial actions to address climate change.
7

8 The Convention establishes a collective decision making process where actions,
9 reflecting their common but differentiated responsibilities, are agreed upon by the
10 Parties. Since climate change is a global issue, many analyses adopt the perspective
11 of a single global decisionmaker. It should be recognized that a collective decision
12 making process may not reach the same conclusions as analyses that adopt a global
13 optimization perspective.) A

A Portfolio of Possible Actions to Limit Climate Change

14
15
16
17 The precautionary principle (Article 3.3) and the estimated damages due to current
18 emissions of greenhouse gases (Chapter 6) argue for action beyond "no regrets"
19 measures.⁴ The decisions to be taken in the near future will necessarily have to be
20 taken under great uncertainty. However, these decisions are not very sensitive to the
21 level at which atmospheric concentrations are ultimately stabilized and can be
22 adjusted based on experience, new knowledge and other developments.
23

24 Actions analysed in the literature which countries can take, individually or jointly, to
25 limit climate change and its impacts include:
26

- 27 ■ implementing low cost measures to reduce emissions of greenhouse
28 gases. There is broad agreement that in most countries there are some
29 measures, such as energy efficiency, that can reduce emissions of
30 greenhouse gases at negative to slightly positive costs (Chapter 9).
31 Achieving such reductions may require use of a combination of
32 ~~regulatory, economic and information~~ instruments;) B
- 33
34 ■ phasing out existing distortionary policies, such as some subsidies to
35 fossil fuels, that reduce welfare and, directly or indirectly, increase

36 ⁴ No regrets measures are those whose benefits, such as reduced energy costs and
37 reduced emissions of conventional pollutants, *excluding* the benefits of climate
38 change mitigation, equal or exceed their cost.

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greenhouse gas emissions.⁵ Emissions reductions of 5% to 20% are possible in many countries from phasing out such policies (Chapter 11);

- implementing fuel switching measures to reduce emissions of greenhouse gases;
- implementing measures to enhance sinks or reservoirs of greenhouse gases;⁶
- instituting forms of international cooperation to limit greenhouse gas emissions such as joint implementation and technology transfer;
- undertaking research aimed at better understanding the causes and impacts of climate change. Economic studies suggest that such research can yield high returns (Chapter 2);
- conducting research aimed at improving the cost-effectiveness of climate change adaptation, enhancing energy efficiency, minimizing emissions of greenhouse gases from continued use of fossil fuels, and developing commercial non-fossil energy sources. The cost of non-fossil energy technologies is one of the major determinants of addressing climate change in the long run (Chapters 9 and 10);
- planning, and implementing as necessary, measures to adapt to the consequences of climate change; and
- developing institutional mechanisms, such as insurance, to share the risks of damages due to climate change (Chapters 1 and 2).

An illustrative simulation of global options with marginal costs of up to \$50 per tonne of carbon suggests about 50% of the total reduction/sequestration would be forestry measures, 25% would be through energy conservation and efficiency improvements, and the remainder would come from a mix of renewable energy use,

⁵ Energy prices that do not reflect the externalities associated with energy use can be considered a distortionary policy. Under some circumstances, kerosene subsidies to reduce fuelwood use, can increase welfare or decrease emissions.

⁶ Some actions to increase sinks may have indirect effects, such as a change in albedo. In such cases the net effect of the measure should be considered.

the Convention is to stabilize atmospheric concentrations of greenhouse gases.⁷ Currently, the atmospheric concentration of CO₂ is about 360 ppmv; the pre-

⁷ It is not clear from the Convention whether the ultimate objective is to stabilize the atmospheric concentration of each gas at a particular level or to stabilize greenhouse gas concentrations, expressed in terms of CO₂ equivalents, at a particular level.

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fuel switching, CO₂ removal and disposal, and nuclear energy. The mix of options and the magnitude of the reduction/acquestration relative to current emissions varies significantly by region (Chapter 7).

Opportunities for Action Vary by Country and Over Time

Each country can select a portfolio of climate change actions that reflect its objectives and constraints. The actions taken by a particular country may reflect considerations such as their cost, secondary benefits, the impacts on different socio-economic groups, international equity, intergenerational equity, the expected damage due to climate change or sea level rise within the country, and economic strategies based on development of new technologies. The size of the investment will reflect the country's obligations under international agreements, adjusted for resources transferred to or received from other countries, as well as domestic goals and priorities. A country's climate change actions will also reflect other priorities aimed at sustainable development, including eradication of poverty and increased levels of education.

Governments can and should *adjust* their portfolio of climate change actions in response to new information and developments. Indeed, both the investment in climate change limitation and the mix of policies will probably change over time. That does not imply complete flexibility. Many of the measures involve capital and technology commitments with long life times. Reversing such commitments could be relatively costly, however that risk should be incorporated into the analysis of the options before the commitments are made. This is particularly important for developing countries and countries with economies in transition where significant infrastructure investments will be made over the next few decades.

A Stabilization Objective

Climate change impacts are related to the stock of greenhouse gases (concentration) in the atmosphere, rather than the annual emissions, hence the ultimate objective of the Convention is to stabilize atmospheric concentrations of greenhouse gases.⁷ Currently, the atmospheric concentration of CO₂ is about 360 ppmv; the pre-

⁷ It is not clear from the Convention whether the ultimate objective is to stabilize the atmospheric concentration of each gas at a particular level or to stabilize greenhouse gas concentrations, expressed in terms of CO₂ equivalents, at a particular level.

4	Post-It™ Fax Note	7671E	Date	JAN 20	Page #	1
To		Sally Kane		From		Lori Lousson
Co./Dept.				Co.		
Phone #				Phone #		
Fax #				Fax #		

industrial concentration was about 280 ppmv.⁸ Analyses of emissions profiles consistent with stabilization of atmospheric concentrations of CO₂ within the range of 350 to 750 ppmv "could be attained only with global anthropogenic emissions that eventually drop to substantially below 1990 levels."⁹

The IPCC's six emissions scenarios assume virtually no new policies specifically designed to reduce greenhouse gas emissions (Chapter 12).¹⁰ Three scenarios that span the full range (IS92a, IS92c and IS92e) are compared with the illustrative profiles of anthropogenic emissions consistent with stabilization of atmospheric concentrations in Figure 1. These emissions profiles indicate that at some stage major reductions of CO₂ emissions (of the order of 50% of current emissions) will be required to eventually stabilize concentrations. "Emissions for all stabilization levels studied are lower than those for IS92a and c, even in the first few decades of the 21st century. Emissions for the IS92c Scenario lie between the emissions [profiles] which ... achieve stabilization at 450 and 550 ppmv."¹¹

Stabilization of the atmospheric concentrations of other greenhouse gases at today's levels requires lesser reductions, but nevertheless reductions, of the emissions of those gases.¹² Thus, stabilization of atmospheric concentrations of greenhouse gases will require very low population and economic growth rates (as assumed for IS92c), a major "natural" change in energy technologies, or intervention to reduce emissions and enhance sinks. The effect of the initial commitments of Annex I Parties, assuming that are achieved and continued to 2050, is shown in Figure 2. The current

⁸ ppmv is parts per million by volume, a measure of concentration.

⁹ *Radiative Forcing of Climate Change: The 1994 Special Report of the Scientific Assessment Working Group of IPCC*, Summary for Policy Makers, IPCC, 1994, p. 4. Analyses of emissions profiles consistent with stabilization of atmospheric concentrations of CO₂ at levels lower than 350 ppmv or higher than 750 ppmv are presently not available in the literature.

¹⁰ *The 1994 Special Report of IPCC*, Summary for Policy Makers, IPCC, 1994, p. 7.

¹¹ *Radiative Forcing of Climate Change: The 1994 Special Report of the Scientific Assessment Working Group of IPCC*, Summary for Policy Makers, IPCC, 1994, p. 15.

¹² *Radiative Forcing of Climate Change: The 1994 Special Report of the Scientific Assessment Working Group of IPCC*, Summary for Policy Makers, IPCC, 1994, p. 18 and 20.

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commitments are not sufficient to stabilize atmospheric concentrations of CO₂, except scenario IS92c which has emissions below current commitments, and additional mitigation measures would be needed early in the next century if stabilization at 650 ppmv or lower is accepted as a goal.

Applicability of Cost-Benefit Analysis

A stabilization objective could be based upon an absolute standard, an affordable safe minimum standard, or a cost-benefit analysis. These approaches are illustrated in Figure 3. The absolute standard approach would define a maximum atmospheric concentration of greenhouse gases that is considered to constitute "dangerous anthropogenic interference with the climate system" on the basis of predicted changes to the climate system or of the predicted impacts of climate change *regardless of the cost of achieving this concentration*. Environmental standards designed to safeguard human health are often established using this approach.

The safe minimum standard approach 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. The standard would seek to reduce the risks of climate change to an acceptable level at an acceptable cost. Cost-benefit analysis attempts to value the impacts of climate change and seeks the atmospheric concentration where the marginal value of the net impact is equal to the marginal cost of abatement.

Working Group III was specifically requested to assess whether cost-benefit analysis is applicable to climate change. Cost-benefit analysis was broadly interpreted to include traditional project level cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis and decision analysis. The traditional cost-benefit approach is depicted in Figure 3(c). Cost effectiveness analysis seeks to find the lowest cost option to achieve a specified objective; the marginal cost of abatement curves in Figures 3(b) and 3(c) represent cost-effective options. Multi-criteria analysis is designed to deal with problems where benefits and/or costs can not be valued; it could be used for the approaches described in Figures 3(a) or 3(b). Decision analysis focuses expressly on making decisions under uncertainty and conceptually could be used in any of the approaches described in Figure 3.

Cost-benefit analysis (broadly defined) *could*, in theory, contribute to resolution of three questions facing decisionmakers. These are:

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- By how much should emissions of greenhouse gases be reduced or sinks of greenhouse gases be enhanced?
- When should emissions be reduced or sinks be enhanced?
- What methods should be employed to reduce emissions and enhance sinks?

The large uncertainties surrounding estimates of damages due to climate change (Chapter 6) and the costs of mitigation (Chapter 9) make it difficult in practice to apply cost-benefit analysis to selection of an appropriate stabilization objective at this time. To date there have been few studies of the costs and benefits of stabilizing atmospheric concentrations of greenhouse gases at different levels. Integrated assessment models best suited to such analyses are quite new (Chapter 10).

However, cost-effectiveness analysis can and should be used to evaluate adaptation and mitigation options.

The Benefits of Limiting Greenhouse Gas Emissions and Enhancing Sinks

The benefits of limiting greenhouse gas emissions and enhancing sinks are the climate change damages avoided. Since some increase in atmospheric concentrations from the current level is virtually inevitable, some impacts and damages due to climate change seem unavoidable.

The literature contains estimates of the damages associated with a climate characterized by a globally-averaged 2.5°C warming. The estimates suggest that if such warming occurred now it would impose net damages equivalent to between 1.5% and 2.5% of world GDP on the present world economy (Chapter 6). The regional variation in climate change damage would be substantial. Damage in developing countries is estimated to be at least 2% with a maximum central estimate of 9% of GDP for some regions. Small islands and low lying coastal areas are particularly vulnerable. Climate changes of this magnitude are not expected to be realized for some decades and damages in the interim would be smaller.

Most estimates of the additional damage done by CO₂ emitted *now* range from \$5 to \$25 (1990 \$ U.S.) per tonne of carbon, although a few estimates range up to \$125

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per tonne of carbon.¹³ The models used to develop these estimates are simplistic and are poor representations of dynamic processes, but they reflect the current state of the art. The wide range of estimates reflects variations in models, scenarios, discount rates and other assumptions.

Climate change benefits of emissions reduction measures can be very complex to estimate. Some energy efficiency and fuel switching measures simultaneously reduce emissions of greenhouse gases and sulphate aerosols. The negative radiative forcing from sulphate aerosols is significant. "Tropospheric aerosols have a lifetime of only a few days ... So the atmospheric concentration of aerosols responds rapidly to changes in emissions. Control of sulphate emissions ... would immediately reduce the amount of aerosols in the atmosphere."¹⁴ A recent model analysis finds that replacement of fossil fuels with carbon-free energy sources leads to lower temperature increases in the long run, but higher temperatures in the interim due to the reduced sulphur emissions (Chapter 10).

Costs of Response Options

What matters from a policy perspective is the net cost (total cost adjusted for secondary benefits and costs) of a mitigation or adaptation option apart from its climate change benefits (Chapter 8). A wide range of estimates of the costs of response options is found in the literature. The wide range is due in large measure to differences in assumptions. Alternative views of the costs of emissions reduction are shown schematically in Figure 4. Curve A assumes that there are no reducible market imperfections; thus there are no "no regrets" options. Curves B, C and D all assume market failures exist in one or more sectors that can be corrected by policies that reduce costs and also lower greenhouse gas emissions. Curve B includes only measures whose direct benefits yield net cost savings. Curves C and D incorporate secondary economic and environmental benefits into the calculation of the net cost of the option.

Despite significant differences in views, there is agreement that some energy efficiency improvements (perhaps to 10% to 30% of current consumption) can be

¹³ A tonne is a metric ton or 1,000 kg. \$5 per tonne of carbon corresponds to approximately 0.35¢ per litre of motor gasoline.

¹⁴ *Radiative Forcing of Climate Change: The 1994 Special Report of the Scientific Assessment Working Group of IPCC*, Summary for Policy Makers, IPCC, 1994, p. 24.

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1 realized at negative to slightly positive costs in most countries, depending on the
2 baseline assumptions and the time frame (Chapter 9). Measures to reduce greenhouse
3 gas emissions often yield additional economic benefits (such as reduced traffic
4 congestion) and/or environmental benefits (such as reduced emissions of acid rain
5 and urban smog precursors). The magnitude of these secondary benefits depends on
6 local circumstances. Studies for European countries and the United States indicate
7 that secondary benefits could offset 30% to 100% of abatement costs (Chapter 6).

8
9 The long run costs of addressing climate change will ultimately be determined by
10 the rate of capital replacement, the discount rate and the effect of research and
11 development. Implementation of "no regrets" measures will increase the time
12 available to learn about climate change and to bring new technologies to the market.
13 Infrastructure decisions are crucial because they can enhance or restrict future
14 options and different choices can lead to very different cost outcomes.

15
16 Estimates of the costs of stabilizing CO₂ emissions vary widely as a result of
17 differences in the baseline scenario, the estimated long run costs of mitigation
18 measures, and the date for achieving the stabilization objective. Differences among
19 models are less significant than differences in the underlying assumptions. Indeed
20 widely differing methods can produce quite similar results when calibrated to the
21 same set of input assumptions.

**22
23 Top-Down and Bottom-Up Models**

24
25 In the jargon of modelers "top-down" models are aggregate models, often
26 macroeconomic models, that analyse how changes in one sector of the economy
27 affect other sectors and regions. Early top-down models tended to have little detail
28 on energy consumption, especially at the technology-specific level, but explicit
29 treatment of behaviour and economic interactions. In contrast, "bottom-up" models
30 tended to describe energy consumption in detail, however consumer behaviour and
31 interactions with other sectors of the economy tended to be down played.

32
33 This simple characterization of top-down and bottom-up models is increasingly
34 misleading as more recent versions of each approach have tended to provide greater
35 detail in the areas that were less developed in the past. This convergence means that
36 differences in model results are increasingly driven by differences in input
37 assumptions rather than model structure. Most results available in the literature do
38 not reflect the effects of this convergence of model structure since the evolution in
39 model structure is a relatively recent occurrence.

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Nevertheless, differences in model structure remain important as different models are best suited to answer different types of questions.

Equity and Social Considerations

Equity considerations are an important aspect of climate change policy and feature prominently in the Convention. Inaction is likely to impose costs on future generations and on regions where damages occur, often regions with low greenhouse gas emissions. Action to address climate change is likely to impose some costs on the present generation. Since actions to address climate change are deliberate, explicit decisions can be made as to how to share these burdens. The Convention recognizes the differentiated responsibilities of the Parties, but it does not include an explicit formula for sharing the costs of addressing climate change. It also lists factors to be considered in determining how the burden should be shared and provides for development of mechanisms for sharing the burdens.

Equity issues involved in addressing climate change may be divided into four categories:

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

The Convention offers some guidance on all of these issues, but doesn't resolve any of them.

A variety of ethical principles, including the importance of meeting people's basic needs, are relevant to sharing the burden of addressing climate change. No single rule will command universal agreement. Furthermore, any arrangement may need to change over time to continue to be perceived as equitable and to take new developments into account. Analysts can not prescribe how the burden of addressing climate change should be shared, they can only clarify the implications of different principles.

Precise arrangements for sharing the burden of addressing climate change now and for the future remain to be settled. Countries differ in terms of current greenhouse

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1 gas emissions (see Figures 5 and 6), vulnerability to climate change (Chapter 6),
2 wealth, resource endowments, and institutional capacity to respond effectively. The
3 Convention provides that these circumstances be reflected in differentiated
4 responsibilities. Developed countries have undertaken commitments through the
5 Convention for technology transfer and contributions to the financial mechanism.

6
7 A rigid "north-south" delineation of equity issues is inappropriate and may be highly
8 damaging in the long run, although it permeates much of the debate at present. The
9 implications of climate change for developing countries are different than those for
10 developed countries because the former are generally poorer, have contributed much
11 less to past emissions and still emit much less per capita, have shorter policy time-
12 horizons, often weaker institutions, other urgent priorities, and are generally more
13 vulnerable to climate change. However, there are substantial variations within the
14 "north" and within the "south" in terms of absolute and per capita emissions, the
15 likely impacts of climate change, institutional strengths and preferences, and
16 endowment of natural resources that may be affected by mitigation. Similarly, over
17 the next century some developing countries will continue to make marginal
18 contributions to the problem, while emissions from others may well start to dominate
19 it.

20
21 Countries (such as low lying coastal regions and islands or drylands) and special
22 groups within society (such as the poor, and sometimes women or children, or
23 specific occupations or regions) that are especially vulnerable to climate change —
24 those on whom the costs of abatement and coping would be especially burdensome
25 — merit special attention.

26
27 All Parties have equal status under the Convention. Procedural equity also requires
28 that all Parties be able to participate effectively in international negotiations related
29 to climate change. Assistance to enable developing country Parties to participate
30 effectively in negotiations would increase the prospects for achieving effective,
31 lasting and equitable agreements on how best to address the threat of climate
32 change.

33
34 Discount Rate and Intergenerational Equity

35
36 The discount rate raises some of the most profound philosophical issues of policy
37 toward climate change, because it confronts the trade-off between the interests of the
38 present and future generations. The discount rate is the mechanism used to make
39 economic effects at different points in time comparable. The choice of discount rate

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1 is important in climate change analyses because the time horizon is extremely long
2 and the abatement costs tend to come earlier than the benefits of avoided damages.

3
4 Economic literature suggests that the proper rate for discounting *consumption* at
5 different points in time and across generations is the social rate of time preference
6 (SRTP). The SRTP is composed of two components, "pure time preference" and the
7 incremental welfare derived from future consumption:

- 8
9 ■ Pure time preference is a reflection of impatience. Although there is
10 debate in the literature, values tend to range from zero to 3%
- 11
12 ■ The incremental welfare of future consumption accounts for rising per
13 capita income over time and the resulting decline in the incremental
14 welfare (marginal utility) derived from the higher future consumption.

15
16 Assuming long term per capita growth rate of no more than 1% per year, the social
17 rate of time preference has been suggested by some authors as about 1.5% per year
18 but various other analysts have suggested values between -0.5% to +6.0% per
19 year.(CHECK WITH REVISED CHAPTER 4). The SRTP discounting approach
20 is equally relevant for developing and developed countries, however, low income
21 countries would be expected to have higher SRTPs initially. Typically the rate of
22 return on private investment will be higher than the SRTP.

23
24 Increasing the discount rate because of risk is generally inappropriate. Because one
25 component of the SRTP can involve uncertainty about the future growth rate, risk
26 considerations might justify *reducing*, rather than raising, the SRTP. However,
27 because the relative price of environmental services is likely to rise over time the
28 effective discount rate for environmental services can be lower than the goods
29 discount rate, and even negative.

30 31 Policy Instruments

32
33 A clear distinction needs to be drawn between actions to reduce the impacts of
34 climate change and actions to reduce emissions. The former also involve
35 consideration of adaptation policies.

36
37 Policy instruments designed to mitigate climate change need to be assessed at the
38 international and domestic levels. Such instruments can help participating countries
39 comply with multilateral commitments on climate change abatement, including
40 international transfers of resources and technology. The international and domestic

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1 policy instruments need not be the same, but international agreements may constrain
2 the choice of domestic policy instruments.

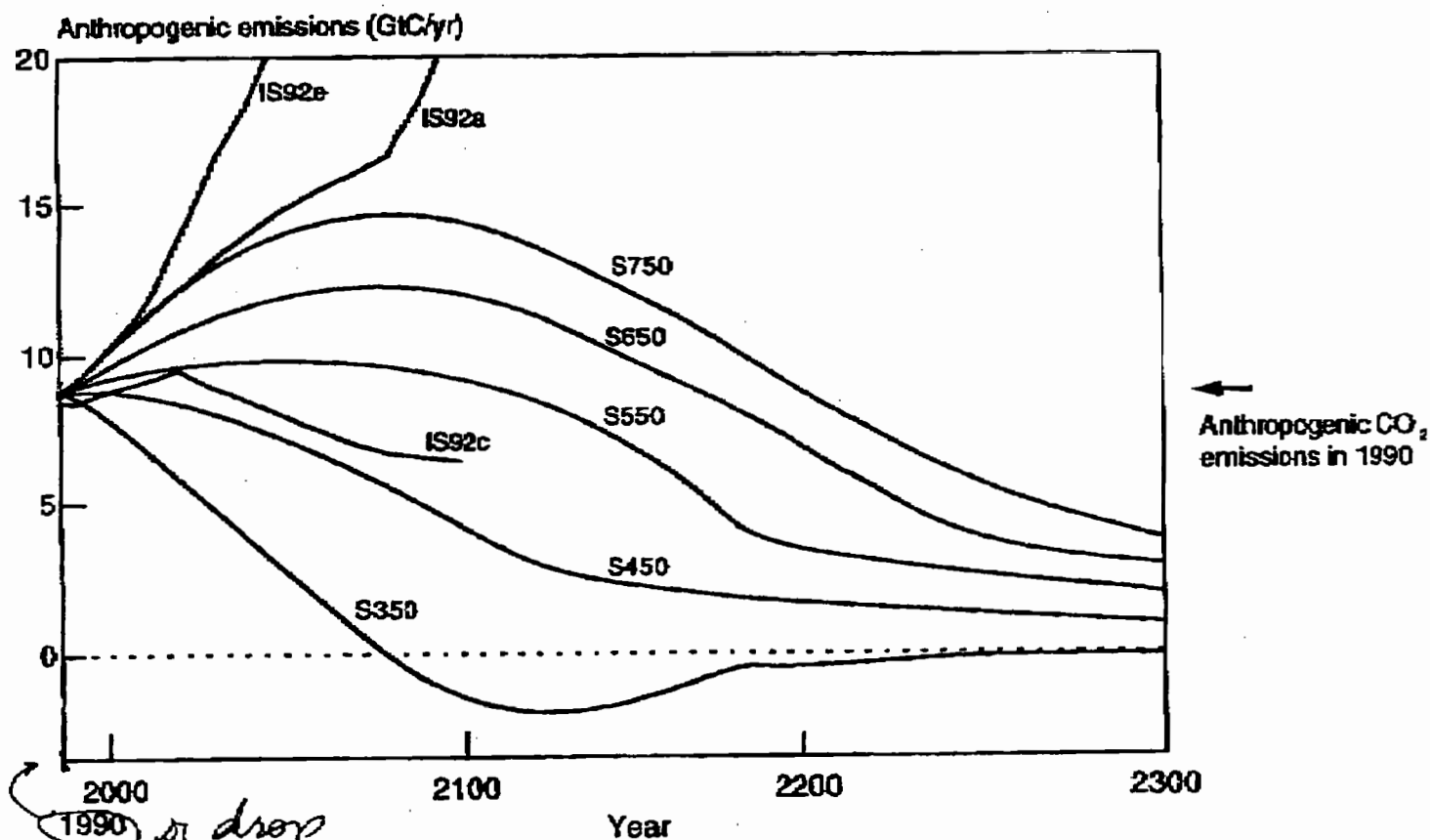
3
4 The policy instruments available internationally and for adoption by groups of
5 countries include: non-tradeable quotas, tradeable quotas, joint implementation,
6 harmonized domestic carbon taxes, international carbon taxes, various international
7 standards and technology transfer. Domestic policy instruments include carbon taxes,
8 tradeable permits, deposit-refund systems, technology standards, performance
9 standards, product bans, voluntary agreements, energy taxes, energy efficiency
10 subsidies, non-fossil fuel subsidies, and removing existing market distortions.

11
12 Among the criteria that governments can consider when selecting from among the
13 available policy instruments are: distributional (including intergenerational) equity,
14 flexibility in the face of technological change and new information, efficiency or
15 cost-effectiveness, compatibility with the institutional structure and existing policies,
16 and understandability to the general public. A mix of instruments may be needed to
17 achieve the best results. Governments may apply different criteria with different
18 weights to the selection of international and domestic policy instruments.

19
20 Cost-effectiveness should always be a criteria for selecting policy instruments, but it
21 becomes more important at both the international and domestic levels as the
22 abatement effort becomes more stringent. The economic literature suggests that the
23 more economically efficient instruments include carbon taxes and tradeable quotas.
24 The consequences of climate change policy will be determined by the choice of
25 policy instrument as well as the design and implementation of those policies. The
26 effectiveness of policies will also depend on their acceptability to the public and to
27 governments.
28

Figure 1

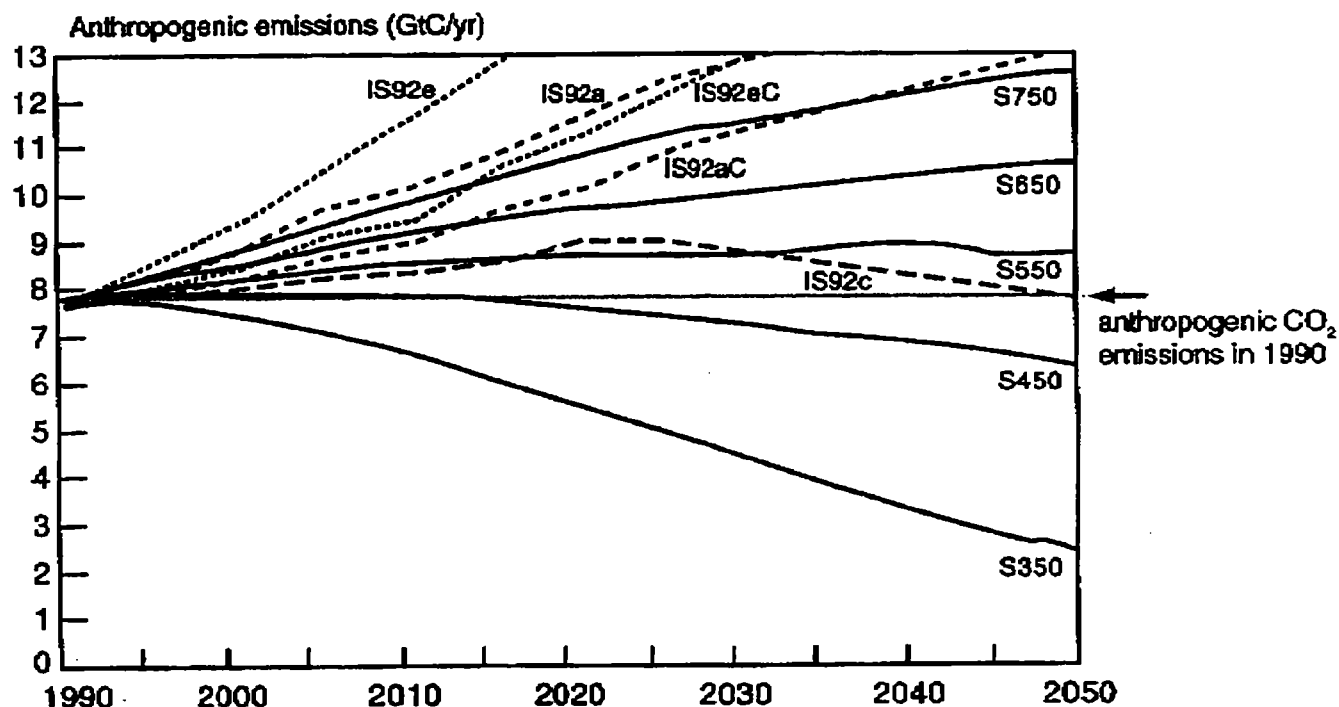
Illustrative Anthropogenic Emissions Profiles of CO₂ Leading to Stabilization at Concentrations of 350 to 750 ppmv Using a Mid-range Carbon Cycle Model and CO₂ Emissions for the IS92a, c and e Scenarios



Source: 1994 Special Report of the IPCC

Figure 2

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

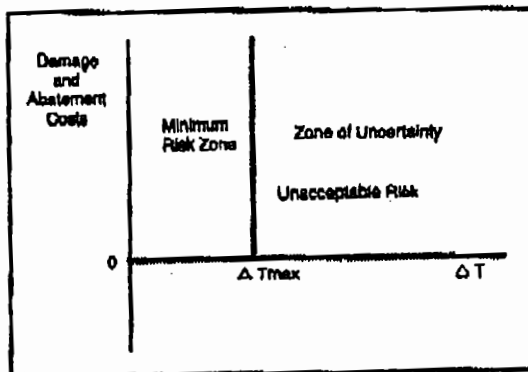


Legend: IS92aC ~~and~~ (IS92eC)

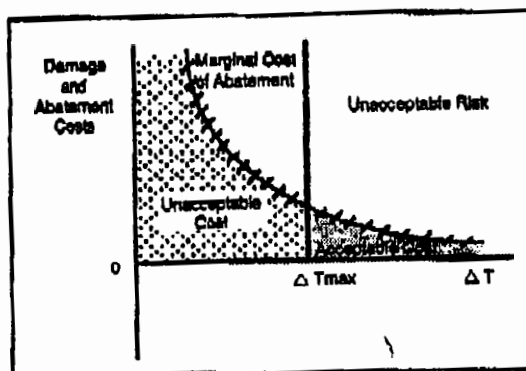
is ~~the~~ scenario IS92a (IS92e) Source: Based on Chapter 12
adjusted for current commitments ~~by~~ Annex I Parties
extended to 2050

Figure 2.3

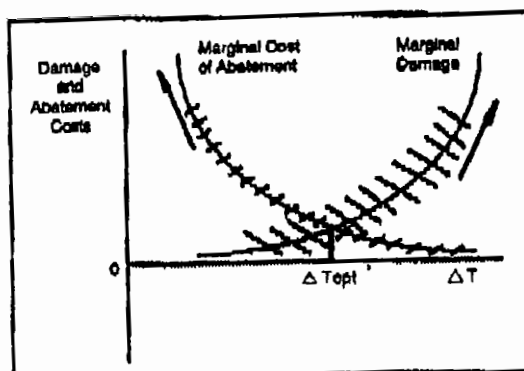
Global Warming, Cost-Benefit Analysis and Sustainable Development



(a) Absolute Standard Approach



(b) Safe Minimum Standard Approach



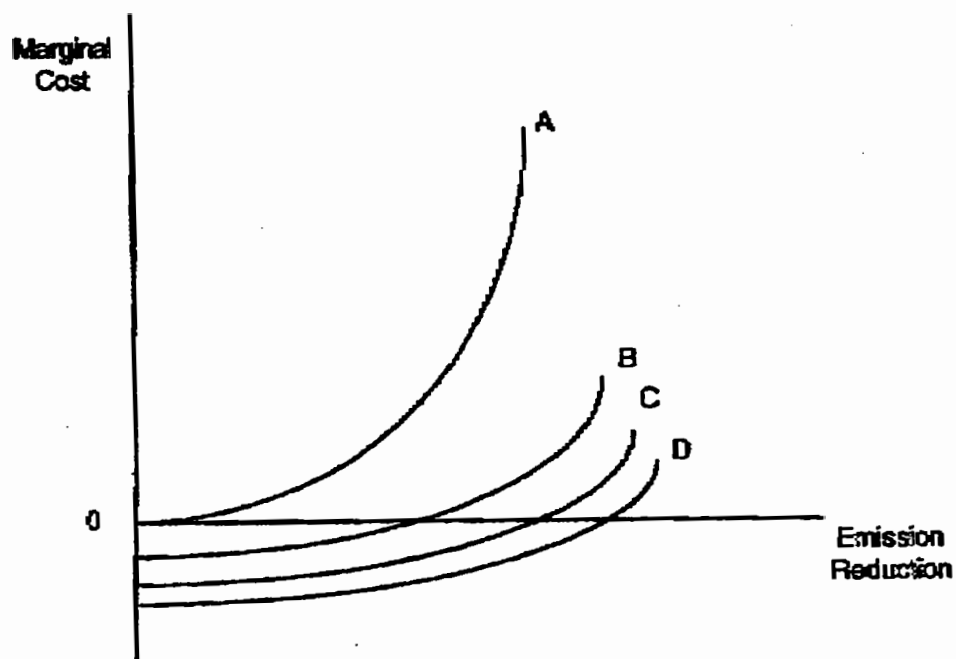
(c) Cost-Benefit Approach

Source: Chapter 6

938008.figs.1/93.4p

Figure 8.4

Alternative Views on Costs of Emission Reduction

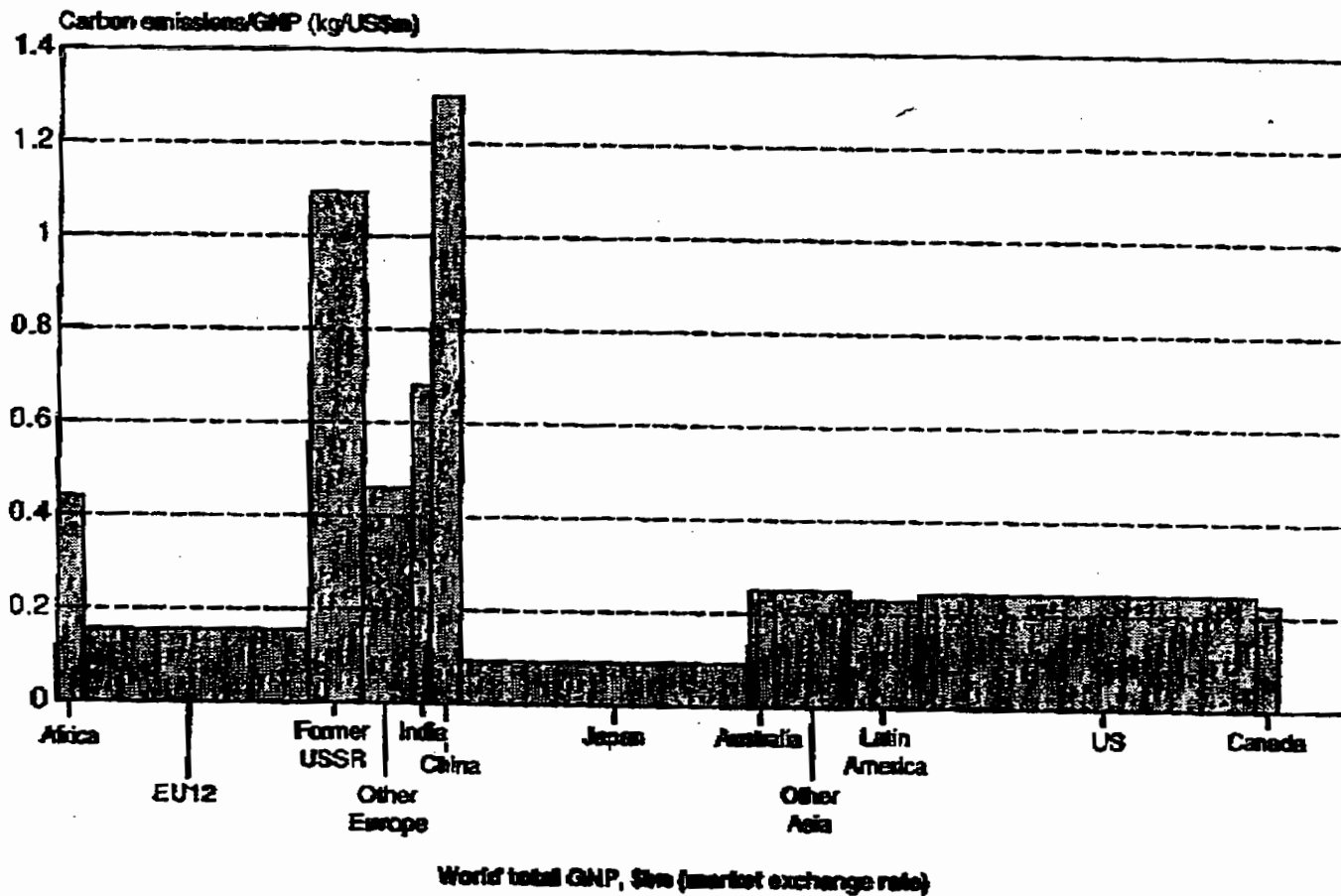


- A - No reducible market imperfections
- B - "Negative cost potential" achieved
- C - Curve B plus "economic double dividends"
- D - Curve C plus "environmental double dividends"

Source: Chapter 8

Figure #16

Carbon Emissions/GNP and Total GNP, 1992



1995, Apr. 1995

Source: Chapter 3



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ac:RS

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Joe, here are my proposed
revisions. They basically sharpen the
core argument. Let me know if you
disagree.

Best

Bill

W Cline
1-23-95

Suggested revisions to January draft of discount chapter.

1. Page 6, line 6. Add the following at the end of this paragraph:

In short, all effects are converted to their consumption equivalents (as discussed in section 3.6), and then discounted at the S RTP.

2. Page 11, line 1. Insert "as low as" before "one quarter of one percent"

3. Page 11, line 9.
change to

... illustrates ~~and as discussed below with respect to shadow pricing capital~~. Most global warming ...

4. Page 12, line 12. Add the following:

However, as shown in the box, the real return on treasury bills has been close to zero. This return is conceptually the closest to that at which households can transfer consumption over time without risk. It thus matters crucially, even in the descriptionist approach, whether the relevant discount rate is that for investment, that for consumption, or some mixture of the two (section 3.6 below).

5. Page 12, line 49.

Replace "It is sometimes argued ... not feasible." with the following:

In the context of climate change, the central argument of the prescriptionists is that other alternatives are not feasible. As suggested in the previous box, it is implausible that society can undertake a firm commitment over a three-century horizon to set aside incremental investments in other capital goods and earmark the proceeds for eventual compensation of those adversely affected by global warming.¹ Even if such a commitment could somehow be

¹ In this important respect, the nomenclature of the two schools should switch. The descriptive school, which emphasizes a positive (observational) rather than normative approach, becomes considerably divorced from what would be the most plausible future behavior, as it implicitly prescribes that all relevant resource decisions should be viewed as solely affecting investment rather than consumption at the margin. Instead, it is much more consistent with positive (descriptive) analysis to assume that resource decisions on an issue this large will broadly resemble those for the economy as a whole, meaning that the great bulk of

entered into credibly, there would be no guarantee that the rate of return on capital would remain as high over this horizon as it is today.

[Paragraph] Accordingly, {if the long-term consumption rate ... (continue original line 50)}

6. Page 14. line 9. Add the following footnote at the end of this line:

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 typical lifetime of capital equipment), with a return of r equal to the rate of return on capital, and discounted at the social rate of time preference (S RTP). With plausible ranges for N , r , and S RTP, the shadow price of capital tends to be in the range of 1-1/2 to 2 units of consumption equivalent per unit of capital.

NOTE: scanning the document, I could not find where footnotes 1 and 4 belong.

NOTE: p. 10 line 7 Pestieau

resources allocated to dealing with climate change will come out of consumption rather than alternative investment. As discussed in section 3.6 below, there is a considerable literature on the importance of determining whether resource sourcing is from consumption or investment.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

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FACSIMILE TRANSMITTAL

cc: Ray S.

Date: January 16, 1995

To: Dr. Joseph Stiglitz

Fax: (202) 395-6958

From: James Bruce

This transmission consists of 11 page(s) including this cover page.
If there is a problem with this transmission, please call (416) 369-0900.

COMMENTS/MESSAGE:

Here are some general points and suggestions for revisions to your chapter. Could you please make as many of these changes as possible and return a revised hard copy and diskette to the Technical Support Unit by Friday, January 20. I apologize for the short turn-around time, however, we must have the final versions of all chapters at that time in order to meet our deadline so we may mail the report for government review next week.

Thank you.

11/17/95

Post-It™ brand fax transmittal memo 7671		# of pages ▶ 11
To	From	
Ray Squitieri	Joe Stiglitz	
Co.	Co.	
Dept.	Phone #	
Fax #	Fax #	



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

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MEMORANDUM

TO: José Goldemberg
Joseph Stiglitz
Ray Squitieri

FROM: IPCC Working Group III Bureau *[Signature]*

RE: Changes to draft chapter 1

DATE: January 16, 1995

A much better chapter! Thanks for the hard work.

Some specific suggestions:

Page	Line	
3		Sometimes confusion in a number of places between greenhouse gases (all) and CO ₂ (or is it CO ₂ equivalent)
3	5	by → before
3	20/21	will → could — "benefits in some economic sectors and damages in others" for some countries
3	23	risk of <u>mid-continent</u> drought and desertification (WGI)
3	31-43	add benefit-cost analysis
3	48-51	drop sentence "This chapter..."

5	8	tangible/intangible: does this mean market/non-market? — refer to chapter 6
5	16-20	future climate range given by WGI (1990) and (1992) reflects the uncertainties
		confuses natural and social sciences — add "well being" to last sentence rather than earlier
5	31-33	disrupt "deep water formation" and the North Atlantic ocean circulation which is
6	12	delete last sentence — suggests leakage > 100% more

		ocean circulation which is
6	12	delete last sentence — suggests leakage > 100%, most estimates are much less
		also effects of high mitigation costs affect economic growth and hence trading partners
6	19-20	all countries will suffer damage, some will also benefit in some sectors of their economy (Chapter 6 suggests no region or country with net benefits)
6	24	"analysts have ..." →(estimates are presented in chapter 6)
6	26-29	delete or focus on costs of <u>change</u>
6	34	add reference to Global Warming Potentials (WGI)
6	36-37	carbon sinks → GHG sinks?
7	box	"uncertainty" — <u>more than 1</u> or "a range of outcomes"
8	45-46	reference Chapter 6 for estimates of regional damage
9	30-33	delete last sentence or balance the argument
9	39	delete "on the model of the Manhattan project" (politically sensitive)
10	41	driving forces for any greenhouse gas, such as CO ₂
10	43 47	consider using the version in endnote 24
11	5	slowly increasing (rather than stable)

- 11 14-15 reword to something like "energy efficiency and GHGs per unit of energy must change to offset per capita output (consumption) and population growth"
- 11 15-16 capital is not directed to GHG mitigation → capital needs to be directed from investments with higher GHG emissions to alternatives with lower GHG emissions
- should note that "Energy efficient development pathways for developing countries have been proposed" — Goldemberg and Reddy, 1988
- 11 31-38 note that for the atmosphere, sustainable stock = stable concentrations and current emissions are estimated to be about 2x emissions consistent with stable concentrations
- 11 40 should → could
- 11 46-49 time period = next century? Coal not exhaustible over this period
- 12 8-9 probably only true over next 2 centuries or less
- 12 34-35 "some other resources" delete, put rest of last sentence as intro to paragraph
- 13 25-28 [While] "Climate... and another" — delete rest
- 13 30-37 polluter pays is another widely accepted principle — should be mentioned
- 14 7-9 Are coordinated taxes - differential tax rates by country that equalize consumer prices in all countries? Or the same tax rate (eg. \$10/tonne C) in all countries. This distinction should be noted in the text or an end note.
- 15 25 chapter 7 is now chapter 11
- 15 33-34 "may actually increase world emissions" - replace with "may be only partially effective"
- Most estimates of leakage are much < 100%
- 15/16 No existing or proposed permit systems allows borrowing of future emissions — rather futures markets and options develop

- 16 20 refer to GWPs
- 16 24-25 Would it be possible to go through each of the components of the Kaya identity — population, per capita output/consumption, energy efficiency, carbon intensity in turn?
- 16 39/40 "likely " is too strong (or delete sentence)
- add mention that high costs of climate change mitigation can affect other countries through trade (ABARE)
- 16/17 47-2 see chapter 11 for fuller discussion of leakages, section 11.6.4.2
- 18 3-7 the word "rights" is a problem — even though everyone emits "GHGs" no one has a "right" to do so. It could also be interpreted as advocating a specific approach to FCCC policy.
- 19 9-16 This discussion is too definitive — "energy prices will rise, land rents will fall in an almost fully offsetting way" (theses are major assumptions not proven)
- Climate change will have many impacts other than temperature - precipitation changes, changes in extremes, etc.
- Assumes perfect competition?
- 19 18-24 The national security discussion is too narrowly focused on emission controls
- climate change itself has national security implications for many countries
- and policies to reduce GHG emissions may have national security implications for energy exporting countries
- 20 4 It should be made clear that these tradeable emission permits are for SO₂.
- 20 26-28 not appropriate for section on within country equity (delete?)
- 21 16 most cost-effective should be "least cost". All measures implemented should be cost-effective. Once negative and zero cost options are exhausted, the lowest cost measures should be selected.

- general conclusions - refer to chapters 8 & 9
- section 1.5.1 revise to be consistent with summaries of chapters 8 and 9 (enclosed)
- section 1.5.2 Policy reform rather than government reform
- 22 23-26 privately generated electricity is also usually price-regulated with price = AC. Historically, this was because economies of scale meant that $HC < AC$ so that with prices + HC the producers would not cover their total costs
- 22 46-49 provide more examples. Add first sentence of endnote 61 to the text
- 24 40-41 this last sentence is too categorical
- Wouldn't section 1.5.2.4 be better as part of section 1.5.3? (some of endnote is good and might be brought forward)
- 26 29 no → less
- 26 1.5.4 The discussion of patents should discuss high patent costs as an impediment to the transfer of technology to developing countries
- 27 10-11 An auction or allocation according to benchmarks (eg. per capita as of a given date) or historical emissions levels (grandfathering).
- 27 28-32 This is well handled in the equity chapter (3)
- 28 1.5.5.1 This section should be reasonably consistent with chapter 9 summary.
- 28 44 Could it be clarified that this section compares energy taxes and carbon taxes to control GHG emissions, not energy taxes to address other energy related externalities such as NOx, VOC, CO emissions.
- 27 Near bottom: should point be made that a carbon tax is difficult to adjust to achieve a specific desired emissions reduction.
- 29 1.5.5.3 tradeable permits better suited to large sources
- 55 refer to results from Chapter 9 — include both "top-down" and "Bottom-up" estimates

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

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

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

III.4 Vulnerability to climate change

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

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

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

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

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

III.5. Social Considerations

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

CHARTER 8

4. Conclusions

- It is important to be clear what types of costs (direct, sectoral, macroeconomic, welfare) are included in the analysis. What matters from the point of view of policy are the net costs, not the total costs of emissions reduction (i.e. the total costs minus any positive side-effects of mitigation).
- It is the insights generated by modelling analyses (e.g. the areas of greatest potential for cost-effective emissions reduction, the directional effect of tax recycling on emissions reduction costs), not the specific numerical results of any one analysis, that matter.
- The size of the costs of mitigation depends critically upon assumptions about the efficiency of the baseline scenario used in the analysis. The higher the underlying economic growth in the baseline scenario, the greater the costs of mitigation. The more emissions reduction built into the baseline, the higher the costs of further reduction.
- Whether a "no regrets" potential for emissions reduction exists depends on whether the economy under consideration is on or below its theoretical production frontier. The existence of a "no regrets" potential implies that (i) significant market failures exist (the society is below the frontier) which give rise to increased GHG emissions, and (ii) that policies can be designed and implemented that correct those market failures.
- There exists a range of quite different socio-economic and technological development paths that would give rise to quite different emissions scenarios and costs of mitigation. Existing energy and emissions models do not address these underlying factors in a very effective way. Future analysis should make use of multiple baseline scenarios to help capture the differences in these factors.
- Infrastructure decisions are critical because they can allow or restrict future options, and different infrastructure decisions can lead to very different cost outcomes. This issue is of particular importance to developing countries, where major infrastructure decisions will be made over the next 25 years.
- Mitigation costing analyses reveal the costs of mitigation relative to a given baseline. The results of different studies cannot easily be compared to each other unless differences in baselines are taken into account. Neither the baseline nor the intervention scenarios should be interpreted as representing likely future conditions.
- There is growing integration of bottom-up and top-down analyses of the costs of energy-related GHG mitigation. This convergence means that differences in results are increasingly driven by differences in input assumptions rather than differences in model structure. Nevertheless, differences in structure remain important as different types of models are best suited to answer different kinds of questions. Substantial disagreement still exists, over the existence and size of a significant "no regrets" potential for GHG emissions reduction.

CHAPTER 9

9.4 General Conclusions

- Estimates of the cost of GHG emission reduction are sensitive to assumptions about appropriate model structure, demographic and economic growth, the cost and availability of energy demand-side and supply-side options, the desired level and timing of abatement, and the choice of policy instruments. Different assumptions have led to a wide range of emission reduction cost estimates.
- Despite significant differences in views, there is agreement that some energy efficiency (perhaps 10-30% of current consumption, depending on baseline assumptions and the implementation time frame) can be realized at negative to slightly positive costs. The existence of such a "no regrets" potential depends upon the existence of substantial market or institutional imperfections that prevent cost-effective emission reduction measures from occurring. The key question is whether such imperfections can be removed cost-effectively by policy measures.
- Energy-related emissions can be reduced through both demand-side (energy efficiency) and supply-side (alternative sources of supply) options. In the short term, demand side options are cheapest in most countries.
- Estimates of the costs of stabilizing CO₂ emissions vary widely as a result of differences both in the baseline scenarios used (e.g. how much energy efficiency or what rate of economic growth is contained in the baseline scenario), and in the calculated costs of various policy measures.
- There has been much more analysis to date of emission reduction potentials and costs for industrialized countries than for other parts of the world. Moreover, many existing models are not well suited to study economies in transition or developing country economies. Much more work is needed to develop and apply models outside of developed countries.
- The overall cost of abatement programs will ultimately be determined by the rate of capital replacement, the discount rate, and the effect of R&D. Appropriate long-run signals to encourage R&D will reduce long-run costs. The implementation of any "no regrets" potential will increase the time available to learn about climate risks and to bring new technologies to enter the market-place.
- Infrastructure decisions are critical because they can enhance or restrict the number and type of future options, and different infrastructure decisions can lead to very different cost outcomes. This issue is of particular importance to developing countries, where major infrastructure decisions will be made in the near term.
- If the climate issue is formulated in terms of stabilizing atmospheric concentrations, the choice of emissions time path is critical in determining the overall price-tag. It is important to identify those paths that minimize the costs of achieving a particular concentrations target.
- The overall impact of a carbon tax will depend not only on the size of the tax, but also on the uses to which the revenues are put. If carbon tax revenues are used to reduce more distortionary taxes, overall emission reduction costs will be reduced. Inefficient tax recycling could, however, increase costs.
- There is need for both detailed (bottom-up) analysis of technological options and also more aggregate (top-down) analysis of economic effects. Whereas historically these two approaches have been associated with very different cost estimates, this need not be the case. Indeed widely differing methods can produce quite similar results when calibrated to the same set of input assumptions.

9 A Review of Mitigation Cost Studies

45

1
2 • Given differences in marginal emission reduction costs among countries, international
3 cooperation can significantly reduce the global price-tag for emissions reduction. Economic
4 efficiency would be enhanced by carrying out emissions reduction where it is cheapest to do
5 so.

6
7 • Estimates of the costs of stabilizing CO2 emissions at 1990 levels in *OECD countries*
8 vary widely. Many bottom-up studies suggest that the costs of achieving this target over the
9 next few decades may be negligible. Given rising baseline emissions over the longer term,
10 however, many top-down studies suggest that the annual costs of stabilizing emissions may
11 ultimately exceed
12 1-2% of GDP.

13
14 • The costs of stabilizing emissions for *economies in transition* may be small relative to
15 OECD countries. The potential for cost-effective reductions in energy use is apt to be
16 considerable but the realizable potential will depend upon what economic and technological
17 development path is chosen. A critical issue is the future of structural changes in these
18 countries that are apt to change drastically the level of baseline emissions and the emission
19 reduction costs

20
21 • Analyses suggest that there may be substantial low-cost emission reduction
22 opportunities for *developing countries*. However, these are likely to be insufficient to offset
23 rapidly increasing emissions baselines, associated with, for example, increased economic
24 growth. In the absence of a highly favorable allocation of carbon emission rights, the likely
25 magnitude of emissions reduction will be particularly costly for developing countries.

11/17/95 Joe: please review marked sections, which contain substantial changes or questions. Ray

INTRODUCTION: SCOPE OF THE ASSESSMENT

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1.1 INTRODUCTION

In recent years, atmospheric emissions of greenhouse gases have risen significantly. Concentrations are currently about 25 percent greater than at the beginning of the Industrial Revolution. If current trends continue, concentrations will double from pre-industrial levels by the end of the next century and, if unchecked, continue to rise thereafter (IPCC 1990).

The scientific community has noted the potentially serious effects of increased concentrations. These climatic effects could, in turn, have further effects on the biosphere, including an increase in mean global temperature, an increase in sea level, changes in agricultural yields, forest cover and water resources, and a possible increase in storm damage.

Increased concentrations of greenhouse gases are the result of fossil fuel burning, livestock raising, and other human activities. Concerted action on the part of individuals and governments will be required to slow the increase in concentrations. Changes in greenhouse gases concentrations and the analysis of the climatic and other physical consequences of those changes lie within the purview of the physical sciences. The role of human activity in generating greenhouse gases, the consequences of those changes for humans, and possible responses, lie within the purview of the social sciences.

Climate change impacts are likely to vary dramatically from country to country. A warmer climate will benefit some mid- and high-latitude countries. At the same time, a rising sea level and the possibility of increased storm surges could threaten the survival of some small island states and coastal areas, and could increase the risk of drought and desertification for inland areas on the periphery of deserts.

Within the past decade, a consensus has emerged on some key issues in the economics of climate change. This report describes areas of consensus, as well as areas of disagreement, the sources of disagreement, and further research that could narrow the range of disagreement. This chapter frames the issue of climate change largely from the point of view of economics but also from that of other social sciences, introducing the more detailed discussions in the chapters to follow.

The commitment of resources to mitigate climate change may rest on one of two arguments. The first arises from fundamental values, the second from decision analysis:

1. We have only one planet. Some changes are largely irreversible, and may occur rapidly. Prudence calls for avoiding a large-scale experiment with the planet. Thus, avoiding climate change lies beyond normal economic calculus.
2. The potential exists for sudden, largely irreversible non-linearities with major effects on the economy, particularly the economy of certain countries or regions.

Even if the first view is adopted, economics has much to contribute to the discussion, for the question of cost-effective emissions reductions must still be addressed. If the second view is adopted, economics will clearly be relevant, both in deciding how much mitigation to undertake, and in designing the measures.

This chapter, and others in this Assessment Report, draw on the findings of Working Groups I and II, and follow the guidelines provided by the Framework Convention. That Convention makes clear that important questions remain to be addressed by subsequent negotiations, including the adequacy of national commitments. This chapter takes the Framework convention as a political document, recognizing that particular terms of the agreements reached by international negotiation may or may not accord with accepted scientific research; that for instance, the agreements may or may not have provided the basis of a cost-effective approach to mitigating climate change. It is hoped that the findings of this chapter and the assessment report more broadly will enhance an understanding of the costs and consequences of alternative

1 actions, and will provide the scientific basis for ongoing negotiations.

1.2 FEATURES OF CLIMATE CHANGE

Climate change could impose a variety of impacts on society. IPCC Working Group II analyses these impacts in detail. They include effects on agriculture¹, forests², water resources³, the costs of heating and cooling⁴, the impact of a rising sea level rise on small island states and low-lying coastal areas⁵, and a possible increase in storm damage. Although most attention to date has focused on negative impacts, some impacts will be positive. Beyond these tangible impacts are a variety of intangible impacts⁶, including damages to existing ecosystems and the threat of species losses⁷.

Climate change presents the analyst with a set of formidable complications: large uncertainties, the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, an irreducibly global problem, wide regional variations, and multiple greenhouse gases of concern.

Large uncertainties. While scientists agree that greenhouse gas emissions are rising, they do not agree about the mechanism linking concentrations, temperature, and well-being. Further, although scientists agree that some warming will occur, they do not agree on the speed of change, or the ultimate amount of change (IPCC 1992, 1994). In addition to these uncertainties, social scientists do not agree on the size of economic effects and behavioral responses to climate change policies.

Nonlinearities and irreversibilities. Nonlinearities occur when changes in one variable cause a more than proportionate impact on another variable. For example, some have suggested that even a modest increase in atmospheric greenhouse gas concentrations could, beyond a certain point, trigger a substantial increase in temperature. Alternatively, even a modest increase in average temperature might significantly increase weather-related agricultural losses because, for many crops, extra days of extreme heat severely limit yields. In Figure 1, if the threshold temperature for crop damage is T_0 , then even a small increase in the mean temperature, from m_1 to m_2 , may greatly increase the number of days above the threshold, represented by the area under the curves to the right of T_0 ⁸. Irreversibilities are changes that once set in motion cannot be reversed, at least on human time scales. "Runaway warming" that some have hypothesized is an example. Some oceanographers have expressed concern that warming might disrupt the deep cold-water current of the North Atlantic Conveyor, responsible for much of the oceans' carbon uptake. Once disrupted, this current might not revert to its original position for centuries⁹.

Long planning horizon. Greenhouse gas concentration changes occur over a long period of time, with the full consequences of actions taken over the coming decades being felt in future centuries. The truly long term nature of the problem is one of the distinctive aspects of greenhouse gas warming. Seldom has the world consciously faced a set of decisions likely to affect our descendants one, two, or three centuries from now¹⁰. Because the costs of taking action today are born by the current generation, while the benefits accrue possibly hundreds of years in the future, the world community is now faced with issues of intergenerational equity on an unprecedented scale. While society has addressed similar problems concerning trade-offs over periods of fifty or even a hundred years, the long planning horizon for climate change puts the analytic questions at issue in a new light. The length of time involved has one further implication: changes in technology, as well as population and consumption patterns, become of paramount importance.

Slow pace of change. Every country has made large capital investments in its cities, farms, ports, etc. Some of this investment cannot be changed without large costs: low-lying port cities, for example, cannot easily be rebuilt. For other investments, the cost of change will be small; for diversified agricultural economies, the cost of switching from one annual crop to another will be small if the temperature increase is on the order of 0.2°C. to 0.3°C. per decade, as climate scientists now expect (IPCC 1994)¹¹.

1 **Inertia in the climate system.** Atmospheric concentrations, rather than emissions, determine the amount
2 of warming that occurs. Concentrations change much more slowly than emissions, meaning that affected
3 nations might not have enough time to prevent warming damage or to mitigate economic impacts after the
4 effects of climate change become evident. In this respect, the risks of climate change are unlike those of
5 earthquakes or floods. The combination of time lags in the climate system and uncertainty about effects
6 requires taking action before unambiguous information emerges about the timing and magnitude of climate
7 effects.

8
9 **Global scope.** Climate change is a global challenge, which cannot be answered by a single country acting
10 by itself. Mitigation must be coordinated globally. In an interlinked world economy, not only are the actions
11 of a single country, or group of countries, not likely to be sufficient to address the problem, they are likely to
12 be largely offset by actions of other countries. If, for instance, one group of countries reduces timber cutting
13 to increase carbon absorption, then the price of lumber will rise, which may induce other countries to
14 increase cutting in their forests. The net impact on world forests may be negligible, or even negative.

15
16 Moreover, whereas economic analysis generally takes the point of view of a single decision maker or
17 government, the important decisions on climate change will of necessity be made by many sovereign
18 governments. Economic and decision sciences are not yet able to predict the outcome of bargaining problems
19 of this type¹².

20
21 **Regional variation.** Impacts are likely to vary greatly both within and among countries. Some countries
22 and regions will suffer from warming; others will benefit. Some cold countries will benefit from a reduction
23 in heating costs and an increase in the length of growing seasons; some warm countries will see a drop in
24 yields from agriculture and forestry; low-lying states are likely to suffer from increased storm surges and
25 flooding. For the world as a whole, the net effect at any time will be the sum of local effects at many points
26 on the globe, some positive and some negative; analysts have no simple way to estimate this sum.

27
28 **Aggregation.** On a priori grounds, there is no reason to believe that greenhouse warming should have in
29 the aggregate, either positive or negative long-run effects (although adjustment implies costs in the short
30 run). Indeed, studies twenty years ago focused on the dire consequences of global *cooling*. It seems unlikely
31 that the earth is somehow endowed at this moment with the *optimal* temperature; the Earth has nonetheless
32 adjusted to its current climate, and readjustments in either direction may be costly.

33
34 **Multiple gases of interest.** Increases in radiative forcing (heat trapping ability) depend on the
35 concentration of all greenhouse gases, not just CO₂, even though most economic modeling to date has
36 limited itself to CO₂. Because different greenhouse gases have different atmospheric lifetimes, analysts have
37 devised weighting schemes to make different gases commensurate¹³.

38
39 **Importance of net emissions.** Because greenhouse gas concentrations depend on net rather than gross
40 emissions, changes in forests and other carbon sinks must be taken into account¹⁴.

41
42 **Efficiency vs. Equity.** How much to reduce emissions is a matter of efficiency. Who pays is a matter of
43 equity. Economics has much to say about the former, but much less about the latter. Nonetheless, equity
44 considerations will drive many of the policy decisions to be made under the Framework Convention on
45 Climate Change.

1.3 CONTRIBUTION OF ECONOMICS

Economics and the social sciences offer perspectives on climate change not provided by the physical sciences. In the classic definition, economics is the study of the allocation of scarce resources that have alternative uses. Economics emphasizes the importance of tradeoffs between different uses of resources, and the foregone value of other uses of a resource, called the opportunity cost. In the context of climate change, this means that 1) costs and benefits matter; 2) resources are not free; and 3) resources used for one purpose are no longer available for other purposes.

***** JOE: The next 2 paragraphs are new. They introduce the CBA framework and arise in the equity discussion later ***** This chapter sets out the logic of cost-benefit analysis as applied to climate change. Cost-benefit analysis requires 1) a valuing of costs and benefits over time, using *willingness to pay* as a measure of value and 2) a criterion for accepting or rejecting proposals. The standard criterion is the *compensation principle* (Kaldor date, Hicks date), which says that if the project yields positive net benefits, then those made better off could compensate those made worse off with something extra left over. The result is an unambiguous gain in welfare, without the necessity of weighing effects on different individuals.

Climate change raises difficulties with both requirements. Valuation is difficult because of the difficulty in valuing environmental amenities, which are generally not traded in the market. And the compensation principle will not apply if mechanisms for affecting transfers do not exist, either between countries or regions in one generation, or -- especially -- between generations. If transfers are not feasible, then the analysis must assign weights to different individuals (for example, the utilitarianism gives equal weight to each person). Only then can conclusions be drawn about net benefits for society as a whole. This issue will arise again in the discussion of equity in section 1.4 below.

Beyond these fundamental concepts are ideas, originally from other areas of economics, that may be applied directly to the study of climate change; this includes work on risk, dynamics, sequential decision making, public goods and externalities, taxation, and general equilibrium.

1.3.1 Risk

The uncertainties associated with climate change are large. Moreover, results available to date from integrated assessment models indicate that climate change risks are highly asymmetrical, with a high probability of a small loss and a low probability of a large loss (Manne and Richels 1992, Peck and Teisberg 1993, Nordhaus 1994). In the past thirty years, much new economic research has focused on rational responses to risk¹⁴, including three areas important to a systematic examination and rational response to climate change: portfolio theory, insurance, and decision analysis.

1.3.1.1 Portfolio Theory

A portfolio manager attempts to get the best return for a given level of risk. One important approach is to buy several types of assets, whose returns are not correlated or are negatively correlated (that is, whose prices move either independently or in opposite directions). In this respect, climate change policy decisions can be compared to investment portfolio decisions.

Several responses can reduce the impact of climate change: insurance and precautionary investments¹⁵. Precautionary investments may take the form of mitigation or in actions that enhance the ability of future generations to adapt. Other choices include agreements for one country to fund emissions reductions in another country (joint implementation), technology transfer and other forms of international cooperation; and phasing out existing policies, such as subsidies to fossil fuels, that reduce welfare and directly or indirectly increase greenhouse gas emissions.

1 A well-chosen portfolio of climate change
2 investments will yield greater benefit for a given
3 cost than any one option undertaken by itself. For
4 an individual country, the issue is how to choose
5 the portfolio of policy measures best suited to its
6 circumstances, and to adjust the portfolio over time
7 in response to new developments. Governments will
8 be making climate change decisions for several
9 decades at least. This means that they will have
10 many opportunities to adjust the size (total
11 resources) and mix (choice of measures) of their
12 portfolio of responses.

13 1.3.1.2 Insurance

14 Several concepts from insurance have important
15 applications to climate change: risk aversion, risk
16 premium, and certainty equivalent.

17 That individuals and societies are *risk averse*
18 means that average utility is increased by pooling
19 risks, or equivalently that people are willing to pay
20 to reduce the risks they face. If society as a whole
21 is risk averse, then some investments with a
22 negative expected return, for example in climate
23 change mitigation, should be undertaken if they
24 reduce the probability of a loss, or the costs of
25 future adaptation.

26 The magnitude of those expenditures depends on (a) society's degree of risk aversion; and (b) the
27 magnitude of the risk. The *risk premium*--the extra amount that society is willing to pay to reduce a risk--is
28 small if the stakes (say, the maximum loss) are small, and large if the stakes are large. An investment of a
29 dollar is justified if it reduces the loss of expected utility by more than a dollar, and not if it reduces the loss
30 by less than a dollar. Thus, results reported below focusing on the expected loss of GDP from climate change
31 do not directly address the risk premium. If a possible outcome is a loss of 10%, even though the expected
32 loss is only 3%, then the *certainty equivalent* loss will exceed 3%. A dollar investment that reduces this
33 certainty equivalent loss by more than a dollar should be undertaken; such an investment could either reduce
34 the average loss, e.g. by reducing the probability of the loss occurring (through mitigation actions) or reduce
35 the variance of the loss. For example, some actions the reduce extreme losses will have more than
36 proportionate returns.

37 The insurance expenditures associated with mitigation actions and investments are, in a sense, only the
38 differences between the actual expenditures and the *no-regrets* benefits (the benefits other than those
39 associated with greenhouse gas emissions). Thus, investments in fuel efficient cars may have a direct benefit
40 in reducing the cost of running a car. The mitigation investment is only the additional investment for climate
41 purposes.

42 The economic principles of risk aversion and portfolio theory provide the rationale for going beyond
43 no-regrets policies. Naturally, actions that reduce greenhouse gas emissions at zero or negative costs should
44 be undertaken. But a prudent response to the risk of greenhouse gas warming goes beyond no-regrets
45 policies to some policies incurring net costs.

Risk and Uncertainty

Uncertainty arises when a decision can lead to more than one outcome.

Expected return or expected value of a decision is the mean of the distribution of returns, the amount a person would on average receive as a consequence of the decision.

Risk aversion measures an individual's unwillingness to take risks.

Risk premium is the amount an individual would pay to replace the uncertain distribution of outcomes with the expected value.

Certainty equivalent is the amount that makes an individual indifferent between it and a risky proposition; for a risk-averse person, the certainty equivalent is higher than the expected return; the difference is the risk premium.

1 Traditional insurance involves pooling a large number of diversifiable risks. Insurance markets *transfer*
2 *risks* from those who are less able to bear the risk to those who are more able to bear the risk, and by
3 spreading the risk among a large number of individuals, reduce the aggregate impact of the risk¹⁶. By
4 transferring risk, traditional insurance can address one aspect of the risk from climate change: the large
5 differences in expected regional impacts. This holds irrespective of who pays the cost, because wealthier
6 individuals and countries are better able to bear risk¹⁷, and because many countries likely to be most
7 adversely affected will be developing countries of the South, while many of the countries least affected (or
8 positively affected) will be the industrialized countries of the North, who could provide insurance for effects
9 of climate change that might fall harder on the South.

10
11 Traditional insurance will not, however, address the dominant risks from climate change. Shipowners can
12 buy insurance against storm loss because one storm is unlikely to sink all the ships covered by the insurer.
13 But homeowners can buy earthquake insurance only from a very large and very diversified insurer. And
14 property owners will not be able to fully insure against the risks of climate change, which is global by nature,
15 and therefore undiversifiable.

16
17 Losses associated with climate change are likely to be both correlated and large, compared to losses
18 absorbed in a single year by the commercial insurance industry. The long term nature of climate change
19 insurance also raises the problem of contract enforcement: will contracts signed today be enforceable
20 tomorrow? Will the insurers be around to pay claims 50 or 100 years from now? (Even in the industrialized
21 countries, private markets may be inadequate to insure against losses from a major national disaster today.)
22 These considerations suggest that private markets may not be able to provide insurance against climate
23 change, and argue for international action to establish insurance markets, perhaps with government
24 reinsurance. Should such an insurance market be established, careful attention will have to be given to
25 ensuring that the insured parties engage in appropriate adaptation actions, mitigating the losses that might be
26 associated with any greenhouse gas warming.¹⁸

27 28 29 1.3.1.3 *Precautionary investments*

30
31 *** JOE: I've rewritten this section *** A business makes precautionary investments to reduce the total
32 risk of its portfolio. Numerous policy measures are available to reduce risks to future generations from
33 climate change. Four have dominated discussions in recent years: 1) immediate reductions in emissions to
34 slow climate change¹⁹; 2) R&D on new supply and conservation technology to reduce future abatement
35 costs; 3) continued research to reduce uncertainties about how much change will occur and what effects it
36 will have; and 4) investments in actions to assist human and natural systems to adapt to climate change if it
37 occurs. Other choices include agreements for one country to fund emissions reductions in another country
38 (joint implementation), technology transfer and other forms of international cooperation; and phasing out
39 existing policies, such as subsidies to fossil fuels, that reduce welfare and directly or indirectly increase
40 greenhouse gas emissions.

41
42 Precautionary investments may also enhance the ability of future generations to react. An important
43 reason that people establish savings accounts is to reduce the impact of unfavorable events in the future.
44 Similarly, a society may elect to accumulate capital against the possibility of a large loss from climate change.
45 This is one thread of the debate over discount rates in Chapter 3. Those who argue for a discount rate close
46 to the opportunity cost of capital point out that society may choose between immediate greenhouse gas
47 mitigation, at a cost, and delayed mitigation, with some of the money saved put aside as a savings account for
48 our grandchildren in the event of large climate-induced damages.

49 50 51 1.3.2 Sequential Decision Making

1
2 ***** JOE: This section is also redrafted ***** As a policy question, global climate change is often posed as
3 a choice between a) doing nothing at all, or b) committing to all-out effort on the model of the Manhattan
4 Project. Given the large current uncertainties about costs and benefits of greenhouse mitigation, this is the
5 wrong way to frame the issue, as it obscures the choices that should be evaluated. Moreover, because option
6 b) may be perceived as too expensive to get political support, policy paralysis often results.
7

8 A more useful formulation is: "Given current knowledge and concerns, what actions should we take over
9 the next one or two decades to position ourselves to act on new information that will become available?"
10 (Lind 1993) For example, decisionmakers would like to know if the possibility of irreversible damages²⁰
11 justifies immediately undertaking an aggressive abatement program²¹.
12

13 Climate change demands a decision process that is sequential and can incorporate new information.
14 Timing will be a key element, and the date of resolution of uncertainty an important element of the analysis.
15 Figure xxx shows schematically the progression from a simple decision to a sequence of linked decisions.
16 The simple decision is sometimes referred to as the "learn, then act" model, the second as "act, then learn";
17 or, in the case of the decision depicted, "act, then learn, then act."
18

19 A sequential decision making strategy aims to identify short-term strategies in the face of long-term
20 uncertainty. The next several decades will offer opportunities for learning and mid-course corrections. The
21 relevant question is not: what is the best course for the next 100 years, but rather: what is the best course for
22 the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.
23

24 For example, the choices might be 1) immediate investment in new plant and equipment 2) aggressive
25 R&D on greenhouse abatement technology or 3) deferring large investment for 10 years, until the nature and
26 size of the threat is better understood, and when costs will presumably have dropped and the job can be
27 done more efficiently.
28

29 Because of the high cost of being wrong in either direction, the value of information about climate
30 change is likely to be great. In particular, the value of information about the sensitivity of temperature to
31 CO₂ increases, the temperature damage function, the gdp growth rate, and the rate of energy efficiency
32 improvement is likely to be high (Chao 1991, Peck and Teisberg 1991, Manne and Richels 1992, Nordhaus
33 1994)²².
34

35 The presence of uncertainty along a dynamic path creates an option value, the value to preserving choices
36 for the future. In climate change, the term has been used in two different ways. One stresses the
37 irreversibilities of climate change; mitigation expenditures now preserve the option of avoiding adaptation
38 expenditure later. The other stresses irreversibilities in investment, and the cost of premature turnover of
39 capital.
40

41 42 1.3.3 Dynamics 43

44 The problem of greenhouse gas warming involves additions to concentrations resulting from net emissions
45 over extended periods of time. Thus the analysis must focus on dynamics. Dynamic analysis involves three
46 stages: the dynamic processes involved, the trade-offs, and judgments concerning those trade-offs.
47

48 Dynamic analyses have lead to important insights. For example, atmospheric concentrations and therefore
49 temperatures depend on the total amount of greenhouse gases emitted over a period of years. A given
50 concentration target can be achieved by a variety of emissions time paths. Time paths that provide for the
51 economical turnover of existing capital stock and time to develop low-cost substitutes are likely to be less
52 costly. This suggests large potential gains from flexibility in timing of emission reductions²³.

1.3.3.1 *Kaya Identity*

The driving forces in carbon dioxide emissions can be seen in the following identity (Kaya 1989):

$$\begin{array}{rcccl} \text{CO}_2 & = & \text{CO}_2/\text{E} & \text{E}/\text{Q} & \text{Q}/\text{L} \quad \text{L} \\ \text{carbon dioxide} & & \text{carbon dioxide} & \text{energy} & \text{output} \quad \text{population} \\ \text{emissions} & & \text{emissions per} & \text{per unit} & \text{per} \\ & & \text{unit energy} & \text{output} & \text{capita} \end{array}$$

or, expressed in rates of change:

$$d \ln \text{CO}_2 / dt = d \ln \text{CO}_2 / \text{E} / dt + d \ln \text{E} / \text{Q} / dt + d \ln \text{Q} / \text{L} / dt + d \ln \text{L} / dt$$

that is, the percentage rate of change in carbon dioxide emissions is equal to the rate of change in carbon dioxide emissions per unit energy plus the rate of change in energy requirements per unit output plus the rate of change in output per capita plus the rate of change in population²⁴.

This identity clarifies different approaches to reducing emissions. For a developed country with a stable population, as long as increases in emissions/output efficiency (emissions per unit energy times energy per unit GDP) keep pace with labor productivity, CO₂ emissions will not increase. Because of the substantial potential for energy efficiency improvements, this seems feasible for most developed countries. Many opportunities exist for increasing end-use efficiency, represented by the second term on the right-hand side, for example from cars to public transportation, from less to more fuel efficient cars and homes²⁵. Fuel switching (for example, from coal-based electricity to oil, gas, hydroelectric, wind, and geothermal), represented by the first term, also offers the potential to limit CO₂ emissions in many countries.

On the other hand, population increases will boost emissions, unless per capita output drops or energy efficiency increases in an offsetting way. For many developing countries with rapidly growing populations pressures for economic development will make it difficult to direct capital to greenhouse mitigation.

On two essential issues evidence is currently limited: (a) to what extent will improvements in energy efficiency require net increases in investment beyond the resources saved from reduced energy usage, i.e., how much does aggressive emission reduction depress economic growth? Order-of-magnitude calculations suggest the presence of only limited trade offs, at least for the near term; (b) do developing countries have the institutional capacity to achieve the desired increases in emissions efficiency?

1.3.3.2 *Non-renewable resources, backstop technologies, and emission reduction strategies.*

Though in principle the atmosphere is a renewable natural resource, the longevity of the greenhouse gases and the relationships between stocks and flows mean that for practical purposes, it may be better treated as an exhaustible natural resource, but one where welfare depends not just on the flow out of the stock, but on the stock itself²⁶.

The central problem with natural resources, whether renewable or not, is timing. Many renewable resources possess a maximum sustainable rate of exploitation. The harvest cannot long exceed this maximum rate without depleting the stock, and ultimately reducing the harvest. Corresponding to the sustainable flow rate is a steady-state stock. If, initially, the actual stock exceeds the steady-state stock, then, for a while, the flow can exceed the maximum sustainable flow. The question is how to distribute this excess over time. Even when the stock is at the sustainable level, in times of emergency, it may be desirable to exceed the

1 maximum sustainable flow. For a renewable resource, this can be done, though only at the expense of
2 decreased flows later²⁷.

3
4 Timing of reductions in greenhouse gas emissions should reflect differences in costs, discounting (to
5 evaluate those costs), and risk. If technological change will make future emissions reductions much less
6 costly, some reductions should be postponed²⁸. With high discount rates, the costs borne by future
7 generations will carry less weight. In the presence of risk, non-linearities, or irreversibilities, the principle of
8 risk aversion suggests a strategy of early mitigation.

9
10 The theory of non-renewable resources has a second set of lessons for climate change policy. There are
11 four broad categories of energy sources: coal, gas and oil, biomass and non-carbon sources. Gas and oil are
12 exhaustible natural resources; hence the amount of total emissions from these sources is limited. With
13 exhaustible natural resources, the question is not how much will be consumed, only when²⁹.

14
15 Figure 2 depicts fuel use in an economy, in three phases. In the first phase, the economy relies on non-
16 renewable resources; in the second, on coal; in the third, on backstop technologies-- e.g., biomass combined
17 with non-carbon sources. The switch points depend on rising energy prices and improving technology, which
18 lowers the costs of the backstops. The figure shows alternative long run scenarios. In panel A, the price of
19 the backstop technology falls sufficiently slowly that for a time, the economy relies on coal. In panel B, the
20 price of the backstop technology falls fast enough to eliminate the intervening stage of primary reliance on
21 coal.

22
23 Since, to a first-order approximation, the total carbon load from the non-renewable resources is fixed
24 (and limited), the total carbon load on the atmosphere is primarily related to coal usage. From this
25 perspective, an important uncertainty is the pace at which the cost of the backstop decreases. If it decreases
26 fast enough, the intermediate stage of coal dependence will be short, and the total carbon load low, while if
27 the price decreases slowly, the carbon load can be much larger.

28
29 From this perspective, conservation of gas and oil is an important part of a risk strategy, for it provides
30 insurance against the possibility of delayed arrival of backstop energy sources.³⁰ This, in turn, has
31 important implications for the "leakage" debate, which asks whether, in the event that the North imposes
32 carbon taxes but the South does not, the South's response will largely offset emission reductions made in the
33 North. It is also possible that lower prices for gas and oil will induce coal-rich countries to decrease their
34 reliance on coal, thus possibly producing negative leakages. But to the extent that occurs, the insurance
35 provided by greater conservation of oil and gas is eliminated, and it is this insurance which should be an
36 essential part of the dynamic strategy. If the backstop arrival is delayed, then the earlier fuel switching by
37 China and India will yield no long-run benefits; while if the backstop arrival is early, the whole issue is
38 largely moot. Leakage needs to be looked at not from a static perspective, of what occurs in a single year,
39 but from a dynamic perspective, corresponding to the long run nature of the global climate problem.

40 41 42 1.3.4 International Public Goods

43
44 A pure public good (Samuelson, 1954) has two properties: the marginal cost of an additional individual
45 using the good is zero (*non-rivalry*), and the marginal cost of exclusion--of stopping an individual from
46 enjoying the good--is prohibitive (*non-excludability*).³¹ The atmosphere has both characteristics. One
47 country's greenhouse gas reductions affect all other countries as well. If this thwarts global warming, all
48 countries benefit³². The atmosphere is in fact an *international public good* in that atmospheric
49 concentrations are the result of combined actions by all countries; some other resources share this
50 characteristic.

Different countries will be affected differently, so that the benefits of avoiding greenhouse gas warming will differ from country to country. Further, some actions will affect simultaneously local atmospheric conditions (providing local public goods) and greenhouse concentrations. For example, actions that reduce urban driving improve local air quality and at the same time reduce greenhouse gas emissions³³.

1.3.4.1 Property rights

An important strand of economic thought associates externalities with a failure to assign property rights (Coase 1990). Assigning property rights to the atmosphere is particularly difficult, since this would require the agreement of many sovereign states. Tradeable greenhouse emission permits, discussed below, can be thought of as an attempt to resolve the problem by explicitly assigning property rights to greenhouse emissions.

1.3.4.2 Paying For An International Public Good

Who should pay for a global public good? every country faces this question internally in determining who should pay for the public goods it provides. Who should, for instance, pay for pollution control within a country?

Economists generally agree on several principles:

First, *concerns about equity should be separated from concerns about efficiency*, though ultimately they are intertwined. An implication of this principle is that because pollution is a social cost of production (and consumption), everyone should be made to pay the full social costs of the pollution they generate. Thus, if there is a social cost to a unit of emissions of greenhouse gases, that cost is the same no matter who produces the emissions. All should pay the full social costs of their actions, whether rich or poor. In this perspective, corrective (Pigouvian) taxes should be imposed uniformly.

Second, *it is inappropriate to redress all equity issues through climate change initiatives*. While climate change should not aggravate disparities between one region and another, neither does it provide a vehicle to remedy these disparities.

Economists agree less about the framework for deciding the burden of financing mitigation and adaptation. At least three approaches have been proposed to determine how the burdens of taxation should be shared. One approach looks at *benefits*: just as those who benefit from private goods must pay for them, those who benefit from a public good should be made to pay for them. The principle has some force when large differences in preferences exist within any income class; providing a particular public good benefits some of those individuals more than others, creating inequalities in the absence of benefit taxes. A major problem frequently encountered, particularly for pure public goods, is that it may be difficult to determine who benefits. It is in general possible to ascertain the *economic benefits* of mitigation, and these are likely to

Public Goods and Externalities

Externality: An externality, or spillover, arises when the private costs or benefits of production differ from the social costs or benefits. Because the social costs or benefits are external to the private costs that firms face, private markets alone the economy will tend to produce too little of a public good (like education) and too much of a public bad (like pollution).

Public good: A public good has two properties: the marginal cost of an additional individual using the good is zero, and the marginal cost of exclusion—of stopping an individual from enjoying the good—is prohibitive. Lighthouses are public goods: when lighthouse services are provided to one person, others may enjoy the same services without cost.

Market Failure: Private markets may sometimes fail to provide a good at the most desirable level: private markets alone will likely provide too few lighthouses and too much pollution.

1 be quite unequally distributed. But this principle, by itself, does not fully determine who should bear the
2 costs: appropriately designed mitigation strategies will produce a surplus of benefits over costs, which must
3 somehow be divided.
4

5 The second approach looks at ability to pay. It is often held that richer countries (or individuals) should
6 pay more than poorer ones. But this principle does not answer the question of how much extra should they
7 pay.
8

9 Economists have turned to a third approach -- the social welfare function -- to answer the question of
10 how much extra different parties should pay, as well as the question of how to distribute the surplus. The
11 discussion of equity below differentiates between the Rawlsian and utilitarian approaches. In this case,
12 both approaches yield similar results: In the absence of incentive problems, both imply that all of the surplus
13 should be allocated to the poorer countries, or that the burden of effort be borne by the richer countries³⁴.
14

15 Yet a different approach holds that social scientists as such have nothing to say about these ethical issues.
16 Coase [1960], for instance, approaches the problem of externalities by emphasizing (a) the importance of
17 assigning property rights, so that, in the absence of bargaining costs, an efficient solution can be obtained³⁵;
18 and (b) that the outcome is independent of how property rights are assigned³⁶. Coase also emphasizes the
19 importance of transactions costs, which will often influence the choice of policies.
20

21 A simple approach that yields efficiency but does not require redistribution (and is thus consistent with
22 the two principles enunciated above) requires coordinated tax rates so that all countries face the same energy
23 prices, with each country retaining the revenues thus generated³⁷. The net cost of such a tax (ignoring the
24 benefits from reduced greenhouse gas emissions) will, in general, be smaller for poorer countries, as a
25 percentage of their national output: the burden of the tax is progressive, even though the tax is levied at the
26 same rate in all countries³⁸.
27

28 *Accounting for past damages.* The Framework Convention on Climate Change directs the Annex I
29 countries to take the lead in responding to the threat of climate change. Some have argued in addition that
30 because the North has been the major contributor to current levels of greenhouse gases, it should bear most
31 of the costs of mitigation. This view says that costs should be borne not in proportion to benefits expected,
32 but in proportion to contribution to pollution. This argument, however, is not based on efficiency, which
33 requires that incentives be prospective (forward looking), not retrospective³⁹. No incentive effects attach to
34 imposing charges based on *past* actions. Whether to charge nations that contributed CO₂ to the atmosphere
35 is an issue of ethics, not efficiency.
36

37 Moreover, many have challenged the ethical basis for assigning responsibility based on past damages⁴⁰.
38 In any case, were it to be applied, the developing countries might eventually pay far more of the mitigation
39 costs than under the other principles described earlier. By the time greenhouse gas concentrations double
40 from preindustrial levels, the developing countries are projected to be contributing more than half of annual
41 emissions, and roughly half of the total stock in the atmosphere (IPCC, 1990; Cline 1992).
42

43 The controversial issue of population growth, while central to the question of economic development,
44 bears on climate change largely through its effect on emissions. This chapter will limit its treatment of
45 population to this one effect⁴¹.
46

47 48 1.3.4.4 *Enforcement* 49

50 Both externalities and public goods need a legal framework within which the problems they pose can be
51 addressed. Without compulsory taxation, there is an incentive for each individual to be a free rider, though

1 there is some empirical evidence that the free rider effect may not be as significant as economists have
2 previously assumed (Bohm [date]). In the absence of compulsory taxation, externalities can only be
3 addressed with well defined property rights (Coase 1990)⁴² and a legal system that enforces compensation
4 for externalities.

5
6 Though in many areas, great strides have been made in the development of an international rule of law,
7 problems are likely to face any system for enforcing climate change agreements. For example, the incentive
8 for free riding is great, whether through delay, nonagreement, or noncompliance. Several alternatives have
9 been proposed, each raising political or economic concerns. No consensus now exists about the relative
10 desirability of these alternatives, though it is clear that some sort of international judicial process will be
11 required to determine and enforce compliance⁴³.

12 13 14 1.3.4.5 Knowledge

15
16 A key element in addressing the problem of global warming is an increase in knowledge--knowledge
17 about climate science as well as about the economic and social aspects of impacts, mitigation, and adaptation.
18 Much of this knowledge is in the nature of an international public good. Developing ways of increasing
19 energy efficiency will benefit all countries. While in some cases, those engaged in the research will be able
20 to appropriate for themselves a significant fraction of the *private* benefits (mostly in reduced energy costs),
21 they will not be able to appropriate the broader social benefits, unless there is a sufficiently high energy tax
22 (or permit fee) that the price fully internalizes the emissions externality. But even then, the social benefits of
23 innovation tend to far exceed the private benefits.

24
25 This suggests the need for an international agreement to fund basic research and subsidize applied
26 research, particularly in energy-related technologies for the developing countries. There need not be a
27 central funding agency, nor a central directorate determining which research should be undertaken. But
28 some mechanism, possibly including joint implementation, must exist for sharing research plans results, and
29 for ensuring that the fruits of this research are made freely available.

30 31 1.3.5 Efficiency

32
33 With some exceptions noted below, issues of efficiency and equity can be separated⁴⁴. Analysts agree
34 that any actions responding to climate change should be cost-effective: no matter who bears the cost of
35 emission reductions, reductions should occur where their cost is lowest⁴⁵. Because of the low energy
36 efficiency in many developing countries, many have proposed that the major effort at the emission reductions
37 be concentrated there.

38
39 Mechanisms for reducing emissions equitably and efficiently, including joint implementation, tradeable
40 permits, and coordinated tax policies, are discussed below and in chapter 7. All of these approaches,
41 however, attempt to confront all individuals and producers in all countries with the same cost of emissions.
42 Emission control is an international public good in that greenhouse emission reductions have the same effect,
43 wherever they occur. Just as efficiency in the production of steel or any other commodity requires that all
44 consumers and producers face the same price, so too with emissions. Uniform prices can be achieved either
45 through coordinated energy taxes or through tradeable permit requirements; but unless the rules are applied
46 in a systematic way to both developed and developing countries, emission reductions will be inefficient.

47
48 Partial participation in an international emissions reduction program, however, *may actually increase*
49 *world emissions*. The growth of international trade has resulted in important links between the developed
50 and less developed countries, and the total effects of any policy undertaken in the North can only be
51 evaluated in terms taking into account the systemic responses, including responses from the South, as

discussed under "General Equilibrium," below⁴⁶.

13.5.1 *Bankable permits*

Efficiency imposes several requirements. One, just described, is that at any moment, the costs of reducing emissions should be minimized. The second is *intertemporal efficiency*: the marginal cost of reducing emissions at two points in time must be the same. If it will cost less to reduce emissions at some future date, adjusting for time discounting, option values (risk), and impacts on atmospheric concentrations, then the reduction schedule should be adjusted accordingly.

One way to provide for intertemporal efficiency within a tradeable permit scheme is to allow banking of permits, i.e. to allow a source to use fewer permits in one year and more in another. A bankable permit system would also address some of the important North-South equity issues. Some developing countries have expressed concern that less aggressive mitigation strategies that will leave a greater burden for the future. Any bankable permit scheme must be accompanied by assurance of future compliance; countries borrowing from the bank must guarantee repayment, perhaps by providing collateral equal in value to the expected future cash value of the tradeable permits borrowed.

13.5.2 *Exchange/risk efficiency.*

When different parties to an agreement hold widely differing views about risk and the probability of loss, significant efficiency gains can result from transferring risk among parties. An earlier section discussed the importance of establishing an international insurance market for those facing the threat of losses under global warming, and noted the advantages of establishing a market within which countries who are less concerned about the economic risks associated with global warming can assume more of the insurance burden. Any efficient international system for addressing the problems of global climate change must include both mitigation and insurance obligations. Governments that believe they have a comparative advantage in assuming climate risks can assume a larger share of those risks, trading off other obligations, and substantially reducing overall costs of responding to climate change.

13.5.3 *Comprehensiveness*

Efficiency also requires that the cost of reducing all greenhouse emissions be minimized. This principle implies that any mitigation program must include all greenhouse gases (taking into consideration their heat-trapping potentials and atmospheric lifetimes⁴⁷), and must include carbon sinks.

Finally, and perhaps most controversially, it implies that mitigation strategies focus on all elements of the Kaya identity above, ensuring that the marginal cost of reductions be the same for each of the possible strategies. Thus, population control may be an element in a long term mitigation strategy no less than a shift in the composition of production or an increase in the energy efficiency of the economy.

13.6 *General Equilibrium*

General equilibrium theory, a cornerstone of economic research over the past century, demonstrates the advantage of looking beyond first-stage effects. It offers two important insights for climate change analysis. First, the various parts of an economic system are interrelated, and perturbations to one part have ramifications for other parts, which may be quite distant. Second, when all of the reverberations are taken into account, the net effect of an action may be markedly different from the initial (and intended) effect.

One implication of general equilibrium theory has already been noted: taxes imposed on one part of the global economy may have little if any effect on global emissions; they may simply result in a relocation of

1 economic activity. Increasingly, the world's economic system must be viewed from a global perspective.
2 Location of economic activities is determined primarily by relative factor prices, taking into account certain
3 specific locational advantages and specialized competencies. If, for example, the OECD countries impose
4 carbon taxes on energy-intensive industries, those industries are likely to relocate outside the OECD.
5

6 If different countries have different obligations to reduce greenhouse emissions, different implicit tax
7 rates will result. This will interfere with world economic efficiency--decreasing world real output--possibly
8 with little effect on total greenhouse gas emissions. For example, the most energy intensive activities--such
9 as aluminum production--may well relocate to developing countries⁴⁸.
10

11 While many of the energy-economy-carbon models described in subsequent chapters attempt to estimate
12 the magnitude of carbon leaks, most are based on standard international trade models, in which the location
13 of production of various goods and machines is fixed (Whalley and Wigle, 1992)⁴⁹. Thus, estimates of
14 carbon "leakages" are based only on commodity substitution⁵⁰. But allowing for relocation of industries --
15 as would occur in the very long run, the time span of interest for an analysis of global warming-- leakages
16 may well exceed 100%. At the current time, no consensus exists among economists on the magnitude of
17 long-run leakages.
18

19 1.3.6.1 *Intertemporal Substitution*

20

21 General equilibrium issues also arise when production can be shifted from one period to another. For
22 example, in a partial equilibrium analysis, a tax on gas or oil raises the price of the fuel taxed, thereby
23 reducing its consumption, and thus associated emissions. But an exhaustible natural resource like gas or oil
24 has, over the long run, by definition an inelastic supply (ignoring for the moment extraction costs, which, in
25 the case of gas and oil, are small relative to the price). The general theory of incidence argues that when a
26 commodity is in inelastic supply, a tax affects the price, but not the level of consumption. That is, *when all*
27 *countries impose a tax on gas or oil, the price of oil falls, by an amount just equal to the tax.* The full
28 incidence falls on producers; as a first approximation, *the level of consumption--and thus the level of*
29 *emissions--remains unchanged.* This provides a first approximation. Obviously, if the tax is large enough, the
30 price will fall below the cost of extraction, and supply will be reduced. Moreover, in the case of exhaustible
31 natural resources, taxes may affect the timing of consumption of the oil and gas (Stiglitz, 1977, 1979, ... ,
32 1993)⁵¹.
33
34
35

1.4 EQUITY

Which nations and which generations hold the rights to greenhouse emissions, and who pays for greenhouse gas abatement and adaptation are among the most contentious issues in climate change. This has immediate implications for policy as well, because the initial allocation of emission rights and emission constraints will largely determine the distribution of costs. The Framework Convention on Climate Change explicitly directs the parties to consider equity:

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

[Account must be taken of] the differences in their starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding [the Convention's] objective⁵².

1.4.1 General Issues

*** JOE: This para is new, and ties in with CBA discussion at the top of 1.3 ***

Within the limits of cost-benefit analysis, equity arises because of the principle of compensation, discussed in section 1.3, above. For example, suppose it could be shown that a business-as-usual path produced higher total benefits than a path with lower greenhouse emissions. We could not from this evidence conclude from this that the world as a whole would be better off. Suppose that costs of warming fall predominantly on one group or one generation, while benefits accrue to another. (For example, some have speculated that the costs of damages from warming would fall largely on the South, without a compensating increase in benefits (Parikh date).) Unless the gainers actually compensate the losers for their losses, cost-benefit analysis cannot conclude that the change has been on balance good for society. Compensation is particularly difficult if future generations would bear most of the costs, because no "Fund for Future Greenhouse Victims" exists (Steer 1992). Thus, some have argued that in the absence of mechanisms to make these transfers, we should not rely on possible future transfers from gainers to losers, but should instead insist that the gainers pay the costs up front.

No consensus exists among either economists or philosophers about the appropriate ethical responses to the changes that would come with global warming. Should, for instance, owners of resources be compensated for the losses that they incur as a result of mitigation actions and the consequent change in prices or values? Economists have often argued no, for several reasons. First, some wealth is not a reward for productive activity, but merely an accident. It is not because country X did something that \$200 billion worth of minerals or oil was discovered to lie beneath its territory. Many would say that these random allocations of wealth have actually contributed to world inequality, and that eliminating a part of these windfall gains would, from the perspective of an egalitarian social welfare function, be welfare-increasing. Another view denies that government policies would be taking away value from assets that by right should be there; until now, according to this view, these resources have simply been overpriced, not fully reflecting the social costs imposed by their use. In this view, actions to discourage overuse would simply rectify a previous mistake.⁵³

Whether investors or countries should be compensated for the adverse effects on their market values remains controversial. There is, however, reasonable consensus on three general principles: First, workers in adversely affected sectors may need assistance to switch occupations (The market failure here is that workers cannot purchase insurance to insure themselves against these kinds of adverse shocks.) Second,

1 gradual transitions may significantly lower the absolute cost of the transition. For instance, workers leave
2 jobs through natural attrition; if those leaving are not replaced, the industry will be scaled down, with no
3 transition cost to any individual worker. Third, the magnitudes of the uncompensated redistributions
4 associated with any change in policy are often correlated with the magnitude of the political opposition.
5

6 Most policy changes produce winners as well as losers. If the relative price of natural gas increases,
7 owners of natural gas deposits may actually be better off. In economies with progressive taxation, either of
8 capital gains or consumption, then implicitly some part of those gains are shared more broadly.
9

10 Virtually all of the policies discussed below also have different effects on different groups of individuals.
11 Those in very hot and very cold climates consume more energy for heating and cooling, and thus would be
12 worse off, relative to those in more moderate climates. In some countries, city dwellers can choose less
13 energy-intensive modes of transport than those in the countryside.
14

15 Many of these impacts will be capitalized. Thus, the value of land in more temperate climates will rise,
16 and the value in more extreme climates will fall. (Similar points can be raised, of course, about the costs
17 imposed by climate change itself.) This capitalization effect has both favorable and unfavorable implications.
18 In the long run, those living in colder climates will consume less heating fuel but at (probably) a higher price,
19 leaving them on balance about where they started. Energy prices will rise and land rents will fall in an
20 almost fully offsetting way. On the other hand, current owners of land will bear the full brunt of the present
21 discounted value of all future increases in taxes (or the tax-equivalent cost of regulations designed to reduce
22 energy utilization.) As a result, unless policy changes are introduced gradually, there may be dramatic
23 changes in land values, and the consequent effects on financial institutions and the economy as a whole can
24 be significant. Offsetting these effects, to some extent, is the *anticipation effect*: property owners do (or
25 should) anticipate some of these changes⁵⁴.
26

27 **National Security.** While countries may be willing (or forced) to accept changes in national wealth as a
28 result of changes in world prices induced by the response to the threat of global warming, countries are less
29 likely to be willing or able to accept what they may perceive as implied threats to national security over
30 which they have some control. Thus, a country with a large endowment of coal becomes more vulnerable if
31 it comes to rely on imported oil or gas--supplies of which could be cut off in times of war. These countries
32 may feel it imprudent to switch, even if private economic gains were to be had; and they are particularly
33 unlikely to switch if the benefits take the form of an international public good.
34

35 Increasing world political stability would clearly address these concerns. But even were that successful, it
36 would not suffice. To increase national security, policies will need to focus on increasing energy efficiency
37 and reducing energy demand. This is an example of the necessity in designing an international structure for
38 greenhouse gas emissions for allowing sufficient flexibility that the particular circumstances of each country
39 can be appropriately taken into account.
40

41 **Benchmarks.** The earlier discussion of equitable distribution of the burdens of responding to greenhouse
42 gases, employing generally accepted principles of public finance, avoided the concept of benchmarks, which
43 have played an important role in international negotiations. Indeed, the "obligations" assumed under the
44 Framework Convention obligates the developed countries to return emissions to 1990 levels by the year 2000.
45 One justification for this form of obligation is that it gives some sense of equity. The difficulty of the task
46 for each country was gauged by its 1990 emissions; requiring each to keep within that target appeared to
47 impose a proportionate burden on each. It was a rough sense of equity, because no attention was paid to the
48 relative incomes of developed countries and therefore no attention was paid to the implied tax rate.
49

50 But in a more fundamental sense this criterion can be criticized as inequitable. It pays no attention to
51 past efforts at achieving energy efficiency, nor to other circumstances that might affect the implied tax rate.

1 For instance, a country which, during the preceding ten years, had made every effort to increase energy
2 efficiency and switch consumption to less energy-intensive commodities would face the burden of reducing its
3 emissions still further. Because the marginal cost curve for emissions reductions rises steeply beyond a
4 certain point, the implied tax rate would be considerably higher than for a country that had previously
5 encouraged overconsumption of energy, for example by energy subsidies. For the second country, achieving
6 the emission targets might require only eliminating the energy subsidies, a policy with an implied negative tax
7 rate. For a similar reason, countries with large endowments of hydroelectric power may find it relatively
8 difficult to meet an emission target of this form.

9
10 Public finance theory has focused extensively on "second-best" policies, recognizing the difficulty of
11 achieving first-best objectives of either economic efficiency or distributive justice. In this context, the central
12 issue is whether there exist alternatives to benchmarking, setting target emission reductions in relation to past
13 emissions. When the U.S. government recently issued tradeable emission permits, for example, it took
14 account of emission reductions already achieved. Benchmarking reflects information that would not be
15 reflected in a simple criteria, such as a particular emission level per unit population or GDP. Thus, a strong
16 case can be made for including benchmarking, if not in the final allocation of permits (obligations), at least
17 in the transition rules.

18 19 **1.4.1 Intergenerational Equity**

20
21 Efforts to control greenhouse emissions will provide benefits primarily for our grandchildren and their
22 descendants. We face a difficult task in estimating and judging what aspects of climate and environment they
23 will value and how best to preserve those aspects for them. If we take aggressive action to limit climate
24 change, they may regret that we did not use the funds to push ahead development in Africa, to better protect
25 the species against the next retrovirus, or to dispose of nuclear materials safely. Chapter 3 addresses directly
26 the most important issue in intergenerational equity: choice of an appropriate discount rate.

27 28 **1.4.2 Within-country Equity**

29
30 While most discussions of equity and climate change have so far focused on North/South issues or on
31 issues between one country and another, issues of equity within a country are also important, and indeed play
32 a central role in the political debates about appropriate responses to climate change. Most policy
33 recommendations involve large within-country losses for certain groups. For instance, any policy leading to
34 less use of coal, and lower producer prices for coal, will lead to large losses for coal mine owners and
35 workers. These issues also arise among countries: countries with large coal deposits will find the value of
36 their natural wealth eroded, and quite naturally will be less enthusiastic about international agreements
37 having that consequence.

38
39 The net efficiency gains (in reduced emissions) relative to the distributive effects may differ markedly
40 across resources. Thus, if elasticity of world oil supply is small, a tax on oil will be reflected in the prices
41 received by producers, and have little effect on cumulative consumption of oil, though it may result in some
42 short-run substitution against coal. Policies aimed at increasing the date of arrival of substitutes for fossil
43 fuels could lead to an increase in current emissions, though long-run effects on atmospheric concentrations
44 would be positive.

1.5 ECONOMICS OF POLICY ACTIONS

*****JOE: Michael Grubb and others jumped on this section for being too narrowly written for economists -- e.g. not presenting the "bottom up" case fairly. Michael is sending me some of his papers that make this case, which I will incorporate. This should improve the reception the chapter receives.*****

Earlier sections set forth a basic framework for analyzing policies related to global climate change, including a combination of mitigation, adaptation, and possibly climate engineering. Striking the appropriate balance requires taking into account the costs, benefits, and risks associated with each strategy. For instance, if risk were irrelevant, governments should reduce emissions to the point at which a dollar of extra spending would yield a dollar of expected savings in damages imposed by climate change, or save an extra dollar of expected costs of adaptation. Adding risk and sequential decision making complicates the analysis but leaves unchanged the basic principles. Because of the lasting impact of climate change, and the magnitude of the resulting economic uncertainties, most policy analysis has focused on a narrower set of questions:

1. What actions would improve economic efficiency (including the social costs of implementing the policy) *and* reduce net greenhouse gas emissions? How much emission reductions could be achieved by these means?
2. Beyond these zero-cost options, what are the most cost-effective methods of reducing greenhouse gas emissions? What does the cost curve look like⁵⁵? What are the alternative policy measures, and how do they compare?
3. What are the essential ingredients of an adaptation strategy, and to what extent will market forces, on their own, provide the appropriate adaptive responses?

1.5.1 Zero-cost Options

A variety of inefficiencies in the energy sector--many of them government induced--would, if eliminated, increase economic efficiency and reduce greenhouse gas emissions at the same time. How large is the reservoir of conservation opportunities? Proponents of the two major approaches to the question have debated this point for more than a decade. *Top-down models* extrapolate observed behavior into the future. *Bottom-up models*, combine engineering analyses to estimate costs with economic models of individual choice. Top-down models generally show significant costs to reducing greenhouse emissions in the future⁵⁶. Bottom-up, or technology-specified models, have been used to show the existence of significant reductions in the cost of energy as new low emissions technologies are adopted. Some proponents of bottom-up models argue that emission reductions can be achieved at essentially no cost, seemingly repealing the long standing economists' presumption that there is no free lunch⁵⁷.

Much of the disagreement turns on empirical estimates. Economists have catalogued the unintended consequences of government regulation. Many have also identified important market failures that could give rise to inefficiencies within the private sector itself. The next two sections will examine each of these effects.

1.5.2 Government Reform

A variety of government reforms could enhance energy efficiency, including removing energy subsidies, reforming or clarifying property rights, reducing non-greenhouse gas externalities, and administrative reforms.

1.5.2.1 Removing Energy Subsidies

Energy subsidies induce inefficient energy use, reducing the total output of the economy as well as increasing CO₂ emissions. These subsidies are especially prevalent in developing countries⁵⁸. Shah and

Larsen (1991) estimated world energy subsidies in 1990 to have been \$230 billion, calculating that their elimination would reduce global carbon emissions by 9 1/2% in addition to improving allocative efficiency thereby generating a welfare gain in subsidizing countries. Burniaux *et al.* (1992) obtained similar results using the GREEN model, concluding that the elimination of all existing distortions on energy markets would yield an increase in world real income of 0.7% per year in addition to cutting world emissions by 18% in 2050. (Dean 1994) Likewise, Unterwurzacher and Wirl (1991) estimated that raising energy prices to world levels in Poland, Hungary, and Czechoslovakia would reduce carbon emissions from those countries by 30%. Agricultural subsidies also distort the outcome, especially affecting the size of forests.

1.5.2.2 *Property Rights Reform*

One responsibility of governments is to define property rights and enforce contracts. Ill-defined property rights encourage overconsumption of resources. A clearer definition of property rights could be particularly important in helping to decrease deforestation, for example, while improving economic efficiency. Uncertainties about *future* property rights may also contribute to economic inefficiency. Thus, for example, in developing countries where large forests are owned by a few large landowners, excessive deforestation may result from landowners' fear that their tenure will be limited.

1.5.2.3 *Administrative Reforms*

Defining property rights and eliminating energy subsidies are two important actions governments can take to reduce greenhouse emissions. At the same time, many less sweeping reforms can improve economic efficiency and simultaneously reduce greenhouse gas emissions. For example:

Pricing of government produced electricity. Many governments price electricity not at the market price but at the cost of production. Economists generally recommend that electricity, like any good, be priced not at its cost of production, but at the competitive price. In countries with a mix of plants, this means that electricity from all sources should be priced the same--at the highest marginal cost of production

Land use and other regulation. Changes in land use policy can also reduce energy consumption (especially for transportation and space conditioning), and thus greenhouse gas emissions⁵⁹.

1.5.2.4 *Revising national accounts*

Some have suggested revising the conventional systems of national accounts to incorporate full social pricing of resources. An early contribution suggested a new measure of economic welfare based on consumption that increases quality of life (Tobin and Nordhaus, 1972). These authors and others recognized that national income accounting, widely adopted after World War II, measures aggregate income and expenditure flows, but does not incorporate environmental costs and benefits.

Conventional national income accounting does not fully report three categories of resource expenditures: a) defensive expenditures, either for pollution prevention before the fact or for cleanup after the fact (although these expenditures are not separately reported, they are counted in GDP); b) consumption of environmental goods (such as exhaustible resources)⁶⁰; and c) conflicting uses of environmental services (such as the atmosphere, used by producers as an input into production, and by households as a consumption good).

One proposal would include in GDP the effect of changes in quality of the environment. In Eastern Europe and the former Soviet Union, steady increases in reported post-war GDP masked the effects of decades of environmental degradation; for part of that period, environment-adjusted GDP almost certainly declined⁶¹.

1 However, important conceptual problems in defining levels and changes of environmental assets,
2 complicate the task of modifying national accounts. First, the stock of natural resources has no obvious
3 definition. While most geologists would agree on the size of coal stocks -- their location is known and their
4 in situ value can be estimated -- this cannot be said for oil or minerals⁶². Second, environmental assets--
5 such as air quality--present another set of problems, because no market prices exist to value the asset.
6

7 Four approaches are commonly used to calculate changes in the natural environment (Peskin and Lutz,
8 1990):
9

- 10 a) The environmental expenditure approach, used recently in the United States, subtracts pollution
11 abatement expenditures from GDP;
- 12 b) The physical accounting approach, used in Norway and France, establishes satellite accounts using
13 physical units of measurement to account for flows and stocks of resources;
- 14 c) The depreciation approach adjusts gross and net product by subtracting out the value of natural resource
15 depletion (Repetto 1989; El Serafy ***); and
- 16 d) The comprehensive approach uses both physical measures and value (Statistical Office of the United
17 Nations, 1992).
18

19 Another measure of broad-based welfare, although not including environmental amenities, is the UN's human
20 development index or HDI (UNDP, 1990). The HDI gives a composite measure of human development by
21 combining three key indicators: longevity (measured by life expectancy at birth), education (measured by
22 adult literacy and mean years of schooling), and income (real GDP per capita adjusted for purchasing
23 power). Although the HDI is not directly related to global environmental issues, both global warming and
24 abatement policies may affect it⁶³.
25
26

27 **1.5.2.5 Regulating Non-greenhouse Externalities**

28

29 Many activities producing greenhouse emissions also generate pollution of other types. For example,
30 fossil fuel combustion releases conventional air pollutants; rush-hour auto use contributes to road congestion.
31 In the presence of these spillover effects or externalities, market solutions will not properly reflect the
32 externalities generated, leading to the overconsumption of environmental resources. Energy taxes, congestion
33 pricing, or tradable permits can correct these market signals, resulting in lower emissions of both greenhouse
34 gases and other pollutants. Some reforms, such as congestion pricing, also reduce the need for roads and
35 other physical capacity.
36

37 **1.5.2.6 Special Problems of Economies in Transition**

38

39 The economies in transition provide special opportunities for mitigating greenhouse emissions. In the old
40 Soviet bloc, high energy subsidies and other price distortions affected energy usage directly, as well as
41 indirectly through the composition of output. Spotty environmental regulation meant that Eastern Bloc
42 nations lacked the environmental controls common in the OECD. The capital shortage of the past decade
43 has contributed to the problem, through a general deterioration of physical capital stock.
44

45 While these problems are largely of governments' making, the remedy is likely to rely on a combination
46 of public and private actions: effective environmental regulation, elimination of government-caused price
47 distortions, and an economic environment in which foreign and domestic investment can enhance the
48 efficiency (including energy efficiency) of the economy. For example, many analysts believe that cutting
49 methane leakage from gas pipelines will yield both high economic and cost-effective reductions in greenhouse
50 emissions.
51

1.5.2.7 Examples of Efficiency-Increasing Policies

Policies that cause individuals not to take into account the full social costs of their actions often result in greater energy use and greenhouse emissions. The National Action Plans of many countries have revealed examples of such policies, and have suggested remedies, including:

Unit pricing of waste disposal to encourage recycling: The *life-cycle* social cost of consuming a good includes its costs of production plus disposal. Most consumers, and many businesses, pay a flat fee for trash disposal; with a flat fee, the marginal cost of throwing away an extra pound of trash is zero. By moving from flat fees to unit pricing, the actual price consumers pay to buy and dispose of a good will more closely match its full life-cycle social cost.

Pay-at-the-pump automobile insurance: In most countries, drivers pay automobile insurance yearly or monthly. Once the premium is paid, the marginal insurance cost of driving an extra mile is zero, even though driving more does increase the chance of being in an accident. As an alternative, drivers could be required to pay a portion of their insurance bill at refueling. With pay-at-the-pump insurance, a tax would be levied on gasoline and earmarked to pay for insurance premiums. This would raise the cost of gasoline at the pump, but lower auto insurance premiums.

Subsidized parking. In some industrialized countries, many employers provide parking to employees at no cost or lower-than-market cost, thus lowering the relative price of commuting by car relative to public transportation. A distortion arises when governments tax income spent on public transportation, but not income implicit in the parking subsidy.

Subsidized housing. In some industrialized countries, home mortgage interest is tax-deductible. In all but a few countries, the implicit income on owner-occupied housing is not taxed. These tax provisions encourage individuals to consume more housing than they otherwise would. In cold or hot climates, where more housing space requires more energy, this tax treatment increases CO₂ emissions.

Subsidized trucking. Studies suggest that virtually all road damage is caused by heavy trucks, which pay only a portion of the expense of building and maintaining the road system. Many countries thus subsidize trucking compared with rail or barge transport, probably increasing greenhouse emissions⁶⁴.

1.5.3 Market Failures and Government Responses

Economists agree that governments can adopt policies to increase economic efficiency at the same time that they reduce greenhouse emissions. For example, in some countries, fuel prices do not reflect the full social cost of fuel burning; taxes can correct this market failure. There is less agreement about whether, *given market prices*, firms fail to take advantage of all of the energy efficiency opportunities available to them. This controversy underlies the bottom-up versus top-down controversy treated at greater length in Chapter 3. Engineers have identified a host of seemingly profitable actions that would also save energy. Many economists, however, view this as evidence that the engineering analysis has omitted characteristics important to consumers. Economists believe that firms do not repeatedly and systematically fail to take advantage of profit-making opportunities.

The substantial differences in practices both within and between countries suggests scope for substantially increasing energy efficiency. Moreover, even best practices within a country may not put it at the technological frontier. In deciding whether to adopt a new production process, businessmen look only at the private costs and benefits. Many technologists, however, conclude that even considering private costs only, firms should be undertaking many energy-efficiency improvements. This section attempts to reconcile the different schools of thought by reference to information-based market imperfections, as well as by the criteria

1 by which businesses make decisions.

2
3 *Information dissemination.* Acquiring information is costly; providing and disseminating information has
4 many features of a public good (Stiglitz 1988, Romer 19 , Arrow). In the absence of government
5 intervention, there will be too little production and dissemination of information. This is particularly true for
6 information with widely dispersed impacts, as opposed to information about, for example, the production of
7 certain chemicals, which is primarily of value to a few companies⁶⁵.

8 Moreover, both theory and evidence support the view that markets, on their own, do not provide an
9 efficient level of disclosure of information⁶⁶. Indeed, some evidence indicates that markets may try to
10 obfuscate relevant information.⁶⁷ This provides the rationale for government provision of information, or
11 laws that in many countries require disclosure of interest rates and other consumer-relevant information,
12 including appliance energy consumption.

13
14 *Bureaucratic structure, limited scope of attention.* In recent years, economic and organizational theory⁶⁸ has
15 emphasized that large organizations are not, in general, run by owners; that the managers, even with the best
16 designed incentives, do not in general maximize the firm's market value; and that one of the principal scarce
17 factors within an organization is time and attention⁶⁹. How managers direct their attention has much to do
18 with what the firm does.⁷⁰ The information disclosures noted in the previous subsection, as well as a
19 number of other government programs focusing on energy efficiency in consumer products, electric lights,
20 and motors, help focus management attention on energy efficiency. The marginal managerial time required
21 to make efficient energy decisions may be small and focusing attention on this issue--when information is
22 being freely provided through government and other sources--may thus yield *private* returns well beyond
23 these slight marginal costs.

24
25 *Returns to Scale and System Effects (network externalities):* Some technologies might be economically
26 attractive at a large scale of production, but not on the much smaller scale on which they might initially be
27 adopted. Other technologies exhibit dynamic scale economies: unit cost falls over time as a function of the
28 cumulative output of firms or industries. Technology "networks" may also affect diffusion rates. For
29 example, cars and trucks fueled with electricity, natural gas, methanol, etc., require a refueling infrastructure,
30 which itself competes for resources with the conventional fuel infrastructure already in place⁷¹.

31
32 *Building codes* can be justified both in terms of these network externalities effects and in terms of
33 information failures. Consumers often have limited information concerning the construction of their houses,
34 and obtaining the information after the house is completed is often difficult. Even were they to be provided
35 with construction details, they would have difficulty interpreting the implications.

36
37 *Capital market imperfections.* A major explanation of the difference between best-practice and
38 actual-practice technology is that bottom-up models often compute cost-effectiveness using a discount rate
39 substantially lower than the cost of capital calculated by firms.⁷² Studies of implicit discount rates
40 consistently show that households and firms use discount rates substantially above market rate for long-term
41 government bonds.

42
43 Two explanations have been offered: 1) Risk: Interest rates facing firms and households reflect the risk
44 premium that lenders require to compensate them for the probability of default. Firms often use discount
45 rates that include a risk premium to reflect the riskiness of projects; 2) Capital constraints: Individuals and
46 firms often face rationing in capital markets, both for credit and equity. Recent research has provided a
47 rationale for this rationing based on the fact that information is imperfect and costly.⁷³

48
49 These capital market problems have one important implication: Models analyzing best-practice cost-effective
50 technologies using discount rates lower than those typically employed by firms will overestimate the rate of
51 dissemination of these technologies and underestimate the perceived costs (to the firms and households

adopting these technologies) of mitigation strategies.

But these capital market problems raise three other questions: (1) Are firms rational in using such high discount rates? (2) Does the use of such high discount rates imply a market failure? (3) If so, will government intervention improve on the market outcome?

Economists emphasize that an analysis of the costs and benefits of a project must separate four issues: timing, risk, capital constraints, and information. Discount rates are only to be used for timing. Risk should be treated by converting costs and benefits into certainty equivalents, then discounting costs and benefits for each year at the relevant discount rate.⁷⁴ Higher risks should not result in higher discount rates.⁷⁵ Similarly, capital constraints should be reflected in the shadow price of capital, not in the discount rate.⁷⁶ Because of limited information (and a version of the "winners' curse"⁷⁷) firms often require threshold rates of return significantly greater than the market rate of interest. In doing so, they may confuse time and information risk: that is, the rules of thumb firms use to evaluate investments may sometimes lead to market inefficiencies, including perhaps in the area of energy-efficient technologies.

Even were firms to follow the economist's guidelines, in the presence of capital constraints, market outcomes would not, in general, be socially efficient (i.e., they are not constrained Pareto optimal.) There may be significant discrepancies between social and private returns to investment (even apart from the externalities associated with greenhouse gases or technological diffusion.) This provides part of the rationale for possible government interventions in capital markets.⁷⁸ Though these capital market imperfections imply that there is no presumption that market allocations are efficient, there is no consensus that they lead to significant underinvestment in energy-efficient technologies in particular⁷⁹.

1.5.4 Innovation

Standard competitive analysis argues that *given all required information and technology* market economies produce efficient outcomes. But recent economic analyses have shown that, in general, market economies need not result in the efficient allocation of resources to information production and dissemination, and to innovation. The first of these issues was discussed earlier. The second is more complex.

In the absence of intellectual property rights, firms would have no incentive to innovate. With standard patent terms, firms are not able to appropriate all the returns to their innovative activity. Setting the optimal patent life involves balancing off the inefficiencies resulting from the exercise of monopoly power during the duration of the patent (static inefficiencies) with the increased incentives for innovation⁸⁰. Largely because innovators seldom appropriate all of the returns to their innovation, there is a general consensus that markets provide insufficient incentives for R & D; and the greater the spill-overs, the greater the undersupply.⁸¹ Since the spill-overs are likely to be greater the more basic the research, this suggests a role for government in subsidizing basic and near-basic research.

Still, there is a general consensus among economists that the patent system provides a better basis of financing applied research than does a system of government grants, largely because of difficulties government has in picking those most likely to produce high returns. The question is, is there any reason to believe that any market failures, in terms of insufficient level of innovation, are worse in this area than in other areas, i.e. are there any special grounds for arguing for government R & D subsidies, provided the government has corrected energy prices to reflect the externalities generated? Obviously, in the absence of such corrections, market incentives to provide energy saving innovations will be distorted, just as market incentives to adopt energy saving technologies are reduced⁸². (Tradeable permits have similar effects to corrective taxes, since firms will value reductions in emissions from new technologies, since such reductions will require them to purchase fewer permits.)

1 Innovation is important, because it provides perhaps the best opportunity for low-cost methods of
2 reducing emissions. Several studies have confirmed the impact of accelerated deployment of advanced
3 energy technologies on the future rate and timing of anthropogenic climate change⁸³.

4 5 **1.5.5 Carbon Taxes and Tradable Permits.**

6
7 Economic efficiency requires all agents in the economy pay for the full marginal social costs of their
8 actions. But in the case of greenhouse gas emissions, firms and households are not charged for the costs
9 they impose. Two economic instruments can correct this market failure: carbon taxes and tradeable permits.

10
11 A tradeable permit scheme involves a determination of the total level of permits and a distribution of the
12 initial allocation. Emission levels for any firm or household are limited to the number of permits they hold.
13 The initial distribution may be performed through a variety of methods, such as an auction or allocation
14 according to historical emissions levels ("grandfathering"). Once the permits are distributed among the
15 companies being regulated, a market is set up wherein the companies may buy and sell the permits according
16 to their plants' individual need to emit. The cost of production then includes not only the costs of
17 conventional inputs, but also the costs of additional permits to offset additional emissions. Plants whose cost
18 of mitigation is low will find it relatively easier to abate pollution rather than to buy permits. Plants with
19 higher costs of mitigation will have a greater preference for buying permits than for abating pollution. The
20 price of the permits, which are artificially created scarce resources, is determined by the market. With the
21 use of tradable permits, companies have an incentive to improve the efficiency of their production, thereby
22 reducing their emissions level, as they can sell excess permits on the market and generate revenue.⁸⁴

23
24 While permits thus create a marginal cost of production related to the marginal emissions, carbon taxes
25 impose a tax directly on the marginal emissions. Both systems thus force producers and households to face
26 the true social costs of their actions⁸⁵.

27
28 The initial allocation of permits will largely determine the distribution of costs of abatement, and at the
29 same time influence the growth path of participants' economies. If for example, countries are given a certain
30 quantity of emission permits per capita every year, the incentive will exist for continued population growth.
31 Alternatively, permits could be issued on the basis of current population, without increasing with changes in
32 population⁸⁶. Or, emission rights could be grandfathered in at current levels, and gradually shifted over to
33 a per capita allocation based on some historical year.

34
35 Imposing carbon taxes can have large distributive consequences. While a system of grants can largely
36 offset these distributive consequences, such offsetting grants might well not be made. Providing tradeable
37 permits equal to existing levels of emissions seemingly makes no firm or household a loser. But granting
38 permits in that way represents effectively a grant of money (such permits have monetary value) in a way
39 which may not well accord with standard ethical principles. For instance, by embarking on an ambitious
40 program to reduce emissions, a firm may qualify for *fewer* permits than it would otherwise. Not only does
41 this violate ordinary notions of fairness, but anticipation of granting permits in this way would, accordingly,
42 have strong adverse effects on emissions⁸⁷.

43
44 That a tax has large distributive consequences, while presenting a political impediment to its introduction,
45 is not necessarily an argument against it. Why should the fact that firms or individuals have failed to pay the
46 full social costs of their actions provide them a greater entitlement? On the contrary, one might argue that
47 they should pay more now because they paid less earlier.⁸⁸

48
49 Once one recognizes that the distribution of permits across countries will, inevitably, be decided by some
50 principle other than current levels of emissions, then it becomes clear that both taxes and tradeable permits
51 will have distributive consequences. An agreement among countries to impose uniform corrective taxes, with

each country retaining its own revenue, would have little redistributive consequences across countries and the burden of the tax would, as noted earlier, *likely be progressive*.

Governments in the North might decide to use some of the revenues so generated to encourage activities (such as R & D directed at technology appropriate for developing countries) that benefit the South, or to provide other forms of assistance. Decisions about this could be made bilaterally, or collectively. By contrast, decisions about how tradeable permits would be allocated across countries would have to be made multilaterally. Arriving at a formula for distributing these property rights may be far more difficult than arriving at a tax rate and a procedure for its revision, as any such formula may entail substantial redistribution.

1.5.5.1 *A Double Dividend?*

Revenues from carbon taxes may allow a reduction in distortionary taxes elsewhere in the economy. If the (compensated) elasticity of demand of labor is relatively high, and the revenues from the carbon tax are used to reduce taxes on labor income, then there would be a *double dividend* from the carbon tax in the reduced dead-weight loss from the labor tax, which would otherwise be significant.

At least three objections have been raised to this idea. First, conceptually: rationalizing the tax system by reducing the most distortionary taxes is certainly a worthy goal, but should not be confused with imposing a carbon tax; neither implies the other. Second, empirically: if the (compensated) labor supply elasticity is relatively low, then the dead-weight loss from the labor tax is low, and the commensurate welfare gain is reduced. Third, politically: if carbon tax revenues are used to offset the existing deficit, rather than to reduce taxes on labor and capital, then the carbon tax acts more like an ordinary tax increase, increasing distortions from taxation to pay for budget items with a lower return than the extra burden imposed. The gains to total welfare (reductions in dead-weight loss) depend on the welfare losses associated with these other distortionary taxes, as well as the cross-elasticities of demand between carbon and other taxed commodities⁸⁹.

Even though carbon taxes may have a positive effect on economic welfare, they can at the same time have a negative effect on *measured* economic growth, since those measures typically do not include the value of environmental degradation. Researchers differ on the size of the loss. The wide spread in the numerical results, however, should not obscure agreement among researchers on a number of important points. All models used in the major comparison studies to date have projected: first, that intervention would be required to achieve the emissions targets; second, that the size of the required tax increases with the stringency of the carbon limit; and third, that the size of the appropriate carbon tax varies over time, even for the same emissions or concentration target⁹⁰.

1.5.5.2 *Energy Taxes*

Energy taxes must be viewed as "second best" taxes in that they do not directly tax the externality, greenhouse emissions. While carbon taxes directly penalize the externality-generating activity, less targeted alternatives, such as energy taxes, may be politically more acceptable. Carbon taxes reduce emissions first, directly, by moving up the demand curve; second, indirectly, by encouraging consumers to switch to less carbon-intensive energy sources. On the other hand, energy taxes work through the first path, by reducing total energy consumption. But to the extent that certain kinds of energy, like hydroelectric, have, at least in the short run, a relatively inelastic supply, a major impact will be on oil, gas, and coal; and to the extent that oil and gas supplies are best described by a model of an exhaustible natural resource, with relatively low extraction costs, most of the supply reduction will occur in coal. Thus, indirectly, there will be a considerable amount of switching, through the indirect effects.

1.5.5.3 Tradeable Permit Markets.

In order for systems of emission permits to achieve reductions in emissions efficiently, there needs to be a market for emissions *across international boundaries*. There is some debate about the role of government or international organizations in establishing a market for such emissions. While some believe that there are private incentives for the establishment of markets, others contend that government can play a key market facilitation role through establishing centralized clearinghouses for information or even provide for permit banking (storage) or brokerage (trading) to facilitate trades between private parties. These services would prove especially useful in the more complex international context.

1.5.5.4 Combining taxes with tradeable permits

While carbon taxes and tradeable permits are typically presented as alternatives, policy makers may prefer to combine them. The major disadvantage is the additional administrative cost. The advantage is more subtle: the market value of tradeable permits is reduced as taxes increase. With an optimal carbon tax, and with a tradeable permit supply set equal to the optimally chosen level of emissions, the price of a permit should be zero. More generally, the greater the tax, the less the value of a permit (for a fixed supply of permits); and thus, the less the distributive consequences of alternative rules for allocating the initial endowments of permits.

1.5.5.5 Intertemporal patterns of taxation

If the target is the long-run atmospheric concentrations of greenhouse gases, then climate change damages will be approximately the same for emissions in any particular year, although the optimal carbon tax must be adjusted for differences in costs, discounting, and risk⁹¹. The focus on concentrations also implies that early reductions are more valuable than later reductions.

For exhaustible natural resources, such as oil, economic efficiency requires that those deposits with the lowest cost of extraction be extracted first. Hotelling [] argued that competitive equilibrium implies that rents (price minus costs of extraction) must rise at the rate of interest. The price of the backstop technology determines the set of resources to be ultimately exploited, i.e. all resources for which the cost of extraction is less than the price implied by the backstop technology's price. Thus, it is the tax on oil or gas at the date of switching to the backstop technology which determines the ultimate amount of oil and gas that will be extracted, and thus the total burden of CO₂ placed on the atmosphere by oil and gas. If that were the only matter of concern, one could simply announce a commitment to impose such a tax sometime in the future, when relevant backstop technologies become available and competitive. That announcement would, if believed, have an immediate effect on current prices.

Figure 3 shows the dynamics of exhaustible resources. S denotes the total available stock of gas and oil. S_0 represents the amount of stock left in the ground, a function of the "backstop" price. Imposing a uniform emission tax lowers the cut-off price, and flattens the price curve. The effect on current price depends on how close the current stock is to economic exhaustion (S_0). Given the currently high levels of rent, it is probable that the net current effect on producers is to *raise* the producer price, not lower it. Thus, short-run leakage effects will be the opposite of that predicted in many models.

1.5.6 Regulatory Approaches

JOE: I will add something here to the section is not just a statement of why command-and-control regulation is bad for your health. Although economists have long argued for the use of economic instruments for environmental management, governments have so far relied on command-and-control regulations almost exclusively, either by requiring a specific control technology, or by regulating inputs or

1 outputs. For example, Corporate Average Fuel Economy (CAFE) standards in the U.S.A. require
2 automobiles to meet certain mileage standards; U.S. electric utilities are required to employ stack-gas
3 scrubbers to remove sulfur.
4

5 Proponents of the traditional approaches often claim that these approaches "force" technology, with less
6 redistribution than forcing technology through taxes. Thus, if automobile makers are required to attain a
7 certain mileage standard, they will meet the standard; on the other hand, gasoline taxes might have to rise
8 significantly to reduce fuel consumption by the same amount. Evidence for this claim of technology forcing,
9 however, is not convincing. In several cases in which industry failed to meet the applicable standards,
10 regulators withdrew the standard in the face of unacceptably high economic costs. The very advantage of
11 technology forcing -- one large club instead of the subtle and continuous incentives provided by market
12 forces -- often proves its undoing.
13

14 Countering this possible advantage are several distinctive disadvantages. First, command-and-control
15 regulations do not in general result in economic efficiency, since those in one sector face implicit or explicit
16 incentives at the margin that differ from those in other sectors. Second, command-and-control regulations
17 fail to account for offsetting private responses that may neutralize the regulation's intended effects and even
18 cause environmental harm. Finally, command-and-control regulations provide no incentives for exceeding the
19 given target, even when doing so might result in little additional cost⁹².
20

21 Command-and-control regulations that focus on inputs and technology rather than outputs have the
22 further disadvantage of not directing research toward meeting performance objectives at least cost. For
23 instance, when scrubbers are required, research will be directed at producing scrubbers at least cost, rather
24 than reducing emissions at least cost. Hence, a dynamic inefficiency is added to the obvious static
25 inefficiencies.
26

27 Finally, because of the nature of the regulatory process, traditional regulatory designs are more likely to
28 be captured by special interest groups⁹³.
29
30
31

1.6 SUSTAINABLE DEVELOPMENT

*** JOE: I have redrafted this whole section*** The concept of sustainable development was formulated about 1980 as a response to the apparent conflict between environmental concerns and the need for economic growth, especially in developing countries. At the time, preserving biodiversity and maintenance of environmental quality seemed incompatible with a 5- or 10-fold increase in world output, as would be necessary if per capita incomes of the South were eventually to approach those of the North now. The sustainable development debate rekindled interest in the question of resource scarcity, originally addressed in the economics literature by Malthus (1798), and revived in the policy arena with the publication of Limits to Growth (1972). A variety of definitions of sustainable development have been proposed. The Bruntland Commission offered this interpretation:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs⁹⁴.

Although the Commission clearly had in mind environmental considerations, its report did not spell out exactly what sustainable development included. The Interamerican Development Bank explicitly included environmental concerns in its formulation:

[Sustainable] development distributes the benefits of economic progress more equitably, protects both local and global environments for future generations, and truly improves the quality of life.

1.6.1 The Economic Concept of Sustainable Development

Although sustainable development began as an ethical principle, it is at the same time an economic concept, focusing on two issues: 1) intertemporal equity and 2) capital accumulation and substitutability.

Intertemporal equity. Robert Solow's definition (Solow 1992), which focuses on intertemporal equity, has enjoyed wide currency among economists: sustainable development requires that future generations be able to be at least as well off as current generations. The central implication is that any environmental degradation should be offset by increases in capital stock sufficient to ensure future generations at least the same standard of living. Sustainable development does not preclude the use of exhaustible natural resources, but requires that any use be appropriately offset.

In practice, sustainability as defined by Solow provides few constraints on growth paths for the developed countries, so long as steady increases in productivity continue. Technical change alone, without further capital accumulation, may well sustain future living standards and offset any effects of environmental degradation. To see this with a numerical example, note that even if estimates of adaptation costs are taken to be 1 to 3 percent of GDP should significant warming occur, and if even moderate rates of technical progress of 1 to 1.5% per annum continue to occur, then future generations 45 to 70 years from now will have twice the income of the current generation. Even with no discounting, it would be hard on this account alone to justify the sacrifice of further consumption by this generation in order to enhance the standard of living of the future generation.

Capital accumulation and substitutability. To what extent can technology, skills, and capital equipment substitute for a decline in exhaustible resource stocks or a decline in per capita environmental amenities? Solow's definition, and much of economic theory to date, implicitly assumes that substitutes exist or could be found for all resources. As formulated by Pearce (1988), 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. If on the other hand, human and natural capital are complements or only partial substitutes (e.g., if because of the irreversibility of extinction, capital accumulation is only a partial substitute for biodiversity) then different classes of assets must be treated differently, and some assets are to

1 be preserved at all costs.

2
3 Pearce (1992?) distinguished between strong and weak sustainability. Weak sustainability requires that
4 any depletion of natural capital be offset by increases in human-produced capital -- the Solow criterion -- or
5 by the substitution of other forms of natural capital, such as renewable assets in place of nonrenewable
6 assets. Strong sustainability requires that some natural capital, being irreplaceable, must be preserved⁹⁵.

7 8 **1.6.2 Implications of Sustainable Development for Developing Countries**

9
10 In many developing countries, Solow's definition would not be viewed as acceptable, since it seems
11 to place no weight on their aspirations for growth and development. Developing countries have also
12 implicitly criticized the debate over substitutability for the same reason: if some natural assets must be
13 preserved at any cost, then there may be no trade off with development. A leading spokesman for the G-77
14 has emphasized the importance of economic growth in achieving sustainable development:

15
16 None of these linked [development] issues can be resolved unless and until there is broad-based
17 development in the South. Only such broad-based development can provide the foundation of
18 international security. The Northern approach is to attack the symptoms, with a residual emphasis on
19 poverty eradication. But the international community must insist on addressing the underlying causes for
20 concern. Development, environmental protection, peace, and security are indivisible⁹⁶.

21
22 Similarly, the G-77 and China emphasized the need for economic growth in the following statement on
23 sustainable development and the environment introduced during the INC negotiations in 1991:

24
25 Protection of the global climate against human-induced change should proceed in an integrated manner
26 with economic development in light of the specific conditions of each country, without prejudice to the
27 socio-economic development of developing countries. Measures to guard against climate change should
28 be integrated into national development programmes taking into account that environmental standards
29 valid for developed countries may have inappropriate and unwarranted social and economic costs in
30 developing countries⁹⁷.

1.7 CONCLUSIONS

Climate change presents the analyst with a set of formidable complications: large uncertainties, the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, an irreducibly global problem, wide regional variation, and multiple greenhouse gases of concern. The risks of climate change are highly asymmetrical, with a large probability of a small loss, and a small probability of a large loss. Even in the presence of significant uncertainty, this asymmetry, plus the principles of risk aversion and portfolio balancing provide the rationale for going beyond *no-regrets* policies to those that incur net costs.

The atmosphere is an international public good, in that all countries benefit from each country's reduction in greenhouse emissions; greenhouse gases are an international externality, in that emissions by one country affect all other countries to the same extent.

Both public goods and externalities require a legal framework within which the problems they pose can be addressed. Mechanisms for control of international public goods may include the definition of property rights, the definition of limits to emissions and a consensus for distributing the same in a fair and equitable manner. If, on the other hand, each agent acts in its individual interest, the result will be too little of the public good and too much of the externality.

Climate change demands a decision process that is sequential, can respond to new information with mid-course corrections, and can include insurance, hedging, and the option value of alternative courses of action. The challenge today is to identify short-term strategies in the face of long-term uncertainty. The question is not, what is the best course over the next 100 years, but rather, what is the best course for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.

Policy measures to reduce risks to future generations include 1) immediate reductions in emissions; 2) R&D on new supply and conservation technologies; 3) continued research on how much change is likely and what its effects will be; and 4) investments to assist in adaptation if significant global warming occurs. A well-chosen portfolio of policies will yield greater benefits for a given cost than any one option undertaken by itself. Striking the appropriate balance requires taking into account costs, benefits, and risks.

In an interrelated global economic system, an attempt to reduce greenhouse gas emissions in one region or one sector of the economy may be offset by increases in other regions or sectors. This may occur through a) the loss of comparative advantage in the carbon-intensive sectors of the regions that limit emissions; b) the relocation of industries; or c) changes in world energy prices and the resulting shift in consumption. Any control strategy must account for these global effects.

Issues of efficiency and equity can largely be separated. The Framework Convention on Climate Change calls on all parties to implement cost-effective measures for abatement, enhancement of sinks, and adaptation. The Framework Convention also explicitly requires an equitable sharing of the burdens of response, recognizing the common but differentiated responsibilities of the parties. Different countries will be affected differently by climate change and by policy responses to it. The South is more likely to be adversely affected than the North; moreover, developing countries often lack the financial and technical resources to respond. The Framework Convention does not, however, include a formula for sharing the costs of addressing climate change.

Efficiency requires that emission reductions occur where their cost is lowest, irrespective of who bears the financial responsibility. Efficiency calls for removing energy subsidies, reforming and clarifying property rights that affect energy use and carbon storage, and reducing non-greenhouse externalities that have the side benefit of reducing greenhouse emissions. Efficiency may also be promoted, and greenhouse emissions

1 reduced, by better information dissemination and by addressing capital market imperfections that inhibit the
2 adoption of energy-efficient technology. Dynamic analysis indicates large potential gains from flexibility in
3 timing of greenhouse reductions to allow for the economical turnover of capital stock, and to allow time for
4 the development of low-cost substitutes. Policies that promote efficiency by requiring nations to face the full
5 costs of their actions will also address equity concerns.
6

7 Efficiency also calls for international mechanisms such as joint implementation and coordinated
8 economic instruments. Coordinated carbon taxes and tradable carbon emission permits can correct the
9 market failure associated with greenhouse emissions.

be: # I have fixed notes 1-9 in accordance with
your 1/6 correction, though, *the drafts*
they are missing from

1.8 ENDNOTES

1.A warmer climate would directly affect the temperature-sensitive sectors of the economy: agriculture, forests, and fisheries; and construction. Because of the risk of drought, arid and semi-arid regions are likely to be most vulnerable to warming. A warmer climate may also encourage insect populations; this, in turn, is likely to decrease agricultural yields in some regions. On the other hand, increased CO₂ concentrations increase photosynthesis and the effect of water consumption in controlled settings, and may also do so in farmers' fields, increasing crop yields.

A warmer climate would hurt agriculture in some regions and help in others. Recent global studies find that Northern temperate regions could benefit, particularly for small increases in temperature, but low latitude areas could lose. The global studies show significant losses from climate change alone that are significantly offset by the direct beneficial effects of higher ambient levels of carbon dioxide on plant growth. Reilly, et al. (1994?) calculate that global agricultural production will increase for global mean warming of up to 2°C.

Most analysts expect that agriculture can adapt without significant added costs for the world as a whole (although some regions will suffer greater-than-average losses), in part because of crop shifting and other adaptation by farmers, and because of the moderating influence of trade in international commodity markets (Ausubel, 1990; Rosenzweig and Parry, 1994; Reilly, Hohmann, and Kane, forthcoming; Kane, Reilly, and Tobey, 1992). Some have concluded that world agriculture would, on balance, benefit from warming of up to 2°C (Reilly 1993).

2.A warmer climate implies both a poleward movement of forests and changes in forest composition. The result would be to increase boreal forests and, by a smaller percentage, to decrease tropical forests. On balance, doubling CO₂ concentrations would modestly reduce both standing biomass and forest area (Sedjo and Solomon, 1989). Some analysts also calculate an additional temporary decline in forest cover during the transition to a warmer climate (EPA, 1989); this decline could last for several hundred years, as more forest death occurs on southern edges than additional growth occurs on northern edges. Higher CO₂ concentrations might also increase tree growth, partially offsetting direct losses from warming.

3.Some analysts conclude that a warmer climate would significantly reduce water supply (Gleick, 1987). Most climate models now predict hotter and drier weather for the mid continents (IPCC, 1990a). If this occurs, the downward pressures on water supply will be intensified by upward pressures on water demand.

Because of the key role of local conditions, further generalizations are difficult. River basin runoff is the difference between precipitation and evaporation plus absorption (IPCC, 1990a). Hence small variations in these three terms--each of which depends on the accuracy of regional climate forecasts--can make a large difference in the runoff.

4. A warmer climate implies reduced heating costs and greater cooling costs. At least for countries in temperate and cool climates, this would move the population-weighted average temperature closer to the ideal indoor temperature. Nordhaus (1991) finds that warming of approximately 3.0°C in a 1981-sized U.S. economy will increase electricity costs by \$1.65 billion and decrease heating costs by \$1.16 billion (1981 dollars), resulting in net costs of \$0.49 billion. Rosenthal, Gruenspecht, and Moran (1994) find that global warming results in a net benefit to the U.S. economy. Cline (1992) finds net costs of \$9.9 billion.

5.Global mean sea level appears to have risen 10-20 cm over the past century (Warrick, Oerlemans *et al.*, 1990). The IPCC has projected a warming-induced rise in mean sea level of 21 to 71 cm by 2070 (IPCC, 1990a), sharply reduced from estimates of 3 to 8 m. made in the early to mid-1980s (Schneider and Chen, 1980; Hoffman *et al.*, 1983; Hoffman *et al.*, 1986). The current "best estimate" for mean global sea level rise by 2030 under "business

as usual" is 18 cm (Warrick, Oerlmans *et al.* 1990; Raper *et al.*, 1990).

A rising sea level could inundate some small island nations, flood some low-lying coastal cities (e.g. in Bangladesh), damage coastal farmland, and contaminate water supplies (IPCC, 1990a). More severe storms would accelerate coastal erosion and affect aquifers, intensifying problems existing today. Warmer oceans might damage coral reefs, a natural defence for some coastal areas. To account for the costs of protective measures, the costs of defending the world's developed coastlines against a 1 m rise over the next 100 years have been estimated to range from 0.01% for the former USSR to 0.74% for Indian Ocean small islands, with a world average of 0.028% of GNP per annum (IPCC, 1992).

6. Some analysts have found tangible costs to be small, and believe that the justification for costly and more restrictive actions rests on intangible costs (Nordhaus, 1993), which remain poorly quantified. Intangible costs include migration, comfort, health, leisure activities, urban infrastructure, and air pollution (Fankhauser ****date****, Cline (1992). A warmer climate would improve human comfort in cold areas, and in the winter generally, while decreasing comfort in warm areas. Mearns *et al.* (1984) calculate a threefold increase in heat waves for a 1.7 degree C. rise in U.S. mean temperature. It is not yet clear whether net comfort will rise or fall for a given rise in temperature.

7. Both the natural rate and human contribution to the process of species loss are difficult to estimate (EPA, 1989). It is even more difficult to predict the effects of climate change on species distribution. Uncertainty about the timing of changes in climate, the duration and type of environmental changes that would be caused by climate changes, and the combination of human and environmental driving forces would influence species diversity make the long-term projection of species change highly complex. Moreover, while some species may have difficulty adapting to climatic changes, opportunities for other species may open up. Population pressures have added to pressure on ecosystems, particularly in the third world. Climate change may exacerbate these damages, particularly in Africa, where environmental degradation has been particularly pronounced during the last 15 years (UN, 1989).

8. A warmer climate might also increase climate variability, though climatologists cannot say with assurance whether climate will become more or less variable daily and seasonally. The normal variability of existing climate also makes it difficult to detect any warming that might be occurring. The "signal to noise" problem makes it possible for observers to mistakenly consider a normal extreme event as evidence of a trend, or to fail to see a trend in a noisy data series. Because of the signal-to-noise problem, the scientific community is unable to indicate confidently whether extremely warm years of the 1980's are evidence of climate change or not (A. Solow 1992 -- check date--).

9. Recent ice core data from Greenland points to earlier temperature rises of several degrees occurring within a few decades (IPCC 1994); reasons for these sudden changes are still not understood, but might have come from changes in deep ocean currents. The other side of this debate holds that on the whole the biosphere is homeostatic or self-correcting; this "Gaia hypothesis" compares the biosphere to a living being: once moved away from equilibrium, self-correcting forces naturally move it back to equilibrium (Lovelock, **date *****).

10. Nations with less diversified agricultural sectors, including small island states, would incur higher costs from such a transition.

11. Although bargaining theory has contributed some basic principles, such as the importance of threatpoints.

12. Scientists do not agree on how to measure the warming potential of different greenhouse gases (IPCC, 1992). Although global warming potential (GWP), endorsed by the IPCC, is a useful concept in formulating comprehensive approaches to greenhouse mitigation policies (Stewart and Wiener, 1990), some analysts have

recently criticized the concept on the grounds that GWP implicitly sets the opportunity costs of an increment in radiative forcing equal for all periods in the future (Schmalensee, 1993). If all greenhouse gases had the same rate of decay, then this problem would not arise.

13. Although forests cannot be expanded indefinitely, and thus increased carbon sequestration is not a permanent solution to increasing greenhouse gas emissions.

14. Frank Knight's often-quoted distinction separates risk, for which the probabilities of different outcomes are known, from uncertainty, in which either they are unknown, or some potential outcomes are not specified. Ref. Knight, Frank, 1922, Risk, Uncertainty, and Profit.

15. This division of responses is from Nordhaus (1994).

16. While most insurance markets do not reduce overall risk, there are a few exceptions: fire insurance companies, by requiring commercial buildings to install sprinklers, do reduce the overall level of losses.

17. This assumes decreasing absolute risk aversion (about which there is a general consensus). Even if northern countries were adversely affected, so long as the adverse effects were proportionately smaller, then, assuming decreasing relative risk aversion (about which there is less consensus), the north would be in a position to insure the south.

Insurance contracts may also be created because of differences in judgments concerning the probability of the insured event occurring. This suggests the potential of an important principle to be invoked in future international negotiations/agreements: countries that believe that the risks of climate change are low, and are therefore seemingly unwilling to take strong actions to mitigate these risks, ought to be willing to provide insurance against climate change at low cost (since it has, from their perspective, an actuarially low value). (See below for a discussion of problems of enforce.) (Heal and Chichilnisky **date, reference**, earlier, Stiglitz **date ** on social risk bearing.)

Insurance markets, if appropriately designed, would have one further advantage: some of the losses associated with climate change are easily avoidable, e.g. construction of durable ocean-front houses. Insurance firms work hard to mitigate the losses that are incurred. Either the insurance should be based on exogenous events (e.g. not on the dollar losses incurred, but on the rise in the sea water), or the insurance companies should be given broad discretion to require the insured to undertake actions to mitigate losses.

18. In the absence of such requirements, strong moral hazard problems arise. It may be desirable to focus government intervention not on the primary insurance market but on the reinsurance market. See recent U.S. government analysis of the market failures and the design of appropriate responses to those market failures in insurance markets for natural disasters.

19. Computer modelers participating in the Energy Modeling Forum examined an "accelerated R&D" scenario in which the cost of nonelectric backstop falls from \$100 to 50\$ per barrel of oil equivalent, and the cost of the electric backstop falls from 75 to 50 mills per Kwh. The four models used were remarkably consistent in their estimates of economy-wide costs, reporting GDP losses falling by 65 per cent for the 20 percent emissions reduction scenario (EMF 1993).

20. For example, low-lying states may suffer permanent damage.

21. Weitzman et al. (1981), cited in Lind (1993), make these points in formulating a sequential decision strategy for developing synthetic fuels.

22. Manne and Richels, Nordhaus, and Peck and Teisberg all report a high value of information on *** and *** in their computer simulations. In addition, *** also reports a high value to information on ***.

Additional References

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Chao, Hung-po, 1992. "Managing the Risk of Global Climate Catastrophe," Electric Power Research Institute.

Peck, S., and Teisberg, T., 1991. "Global Warming Uncertainties and the Value of Information: An Analysis using CETA," Electric Power Research Institute.

23. Richels and Edmonds (1993) provide a demonstration of this proposition; they calculate relatively low costs for stabilizing CO₂ concentrations if flexibility in timing is allowed, compared to capping and stabilizing emissions to achieve the same atmospheric concentration.

24. Alternatively, the Kaya identity may be written

Growth rate of CO₂ emissions = growth rate of output - decline in energy per unit output - emissions per unit energy use

That is, CO₂ emissions will not rise as long as output grows no faster than the combined decline in energy intensity per unit of production and CO₂ emissions per unit of energy use. This formulation applies better to the developed countries.

25. Chapter 8, "Evaluating the Costs of Mitigation," treats the important issue of inertia and technology.

26. That is, for conventional exhaustible resources, there is a stock, S. Welfare depends on flows out of the stock each year:

$U(S_1 - S_0, S_2 - S_1, \dots, S_{t+1} - S_t, \dots)$, where S_t is the stock at the end of period t.

Here, welfare depends *directly* only on the stocks, though indirectly, through the effects on consumption, on emissions, which affect the change in stock:

$U(S_0, C_1(S_1 - S_0), S_1, C_2(S_2 - S_1), \dots, S_t, C_t(S_{t+1} - S_t), \dots)$.

27. Even when the flow exceeds the long-run sustainable level, it will not be optimal to reduce the flow instantaneously, unless -- or even when -- there are zero costs of adjustment.

28. Postponing action may lead to some irreversible damages, for example the flooding of low-lying states.

29. This is not quite correct, since price affects incentives for exploration, and some marginal wells would not be drilled if oil prices fall too low.

30. For analyses of market and optimal responses to uncertainty about the arrival of backstop technologies, see Dasgupta, Gilbert, and Stiglitz [] and Dasgupta and Stiglitz []l.

31. Although for counter examples to the received wisdom see Coase (1990).

32. Formally, if A measures the quality of the atmosphere, then each individual's or country's welfare, U^j , is a function of its own consumption, C^j , and the shared public good, A : $U^j(C^j, A)$. This does not mean that all individual's (country's) value changes in A the same; that is $(\partial U^j / \partial C^j) / (\partial U^j / \partial A)$ may differ in magnitude, and even in sign.

33. Although there may also be trade-offs: reducing those gases that contribute most to local pollution may sometimes be at the expense of increased emissions of greenhouse gases.

34. This kind of optimization problem was first studied by Edgeworth, *Mathematical Psychics* (). The importance of incentive effects for the analysis of distributional issues was first emphasized by Mirrlees (1971) and Fair (1970). There are, obviously, important incentive effects: if the LDCs were able to classify any expenditure that had some effect on mitigation as a mitigation expenditure, with the cost borne by the developed countries, they would have an incentive to undertake excess expenditures of this type. The GEF (Global Environmental Facility) directly addresses this issue, by only providing funds for incremental costs, that is those costs that go beyond what would have been the efficient level of expenditures ignoring the public good benefits of greenhouse gas mitigation.

35. The importance of the assumptions of the absence of transactions costs, including the presence of perfect information, has only gradually come to be recognized. See Farrell [], or Stiglitz [1988] for an elementary textbook treatment.

36. That is, for instance, it makes no difference whether smokers or non-smokers are given the property rights to air. Whether smokers value smoking more or less than non-smokers value clean air will determine whether smoking occurs. How property rights are assigned *does* make an important difference for the distribution of welfare. Coase's result that outcomes are unrelated to the initial assignment of property rights obviously ignore potentially important income effects.

A slight extension of this perspective says that social scientists should simply *describe* the outcome of the bargaining process by which property rights are assigned. Beginning with the important work of Nash [], a variety of bargaining theories have been developed, most of which emphasize the importance of "threat points"--the outcomes which arise in the absence of a bargaining agreement-- to the determination of the eventual outcome. In this case, the fact that the net losses of many developed countries may be limited relative to those of many of the less developed countries suggests a bargaining solution in which much more of the costs of mitigation are borne by the less developed countries than under the "social welfare function" allocations described earlier.

37. For small taxes, these are "compensated" taxes, and have no welfare effect, though they have a substitution effect, and therefore do reduce pollution.

38. The loss in welfare (ignoring the benefits from reduced greenhouse gas warming) are the Harberger triangles, and can thus be shown to be proportional to the product of the elasticity of demand for energy and the share of energy in national output. Since poorer countries are likely to have less access to alternatives which increase the elasticity of demand, and since the share of energy is larger in richer countries, the burden of the tax is

progressive.

39. The *polluter pays principle* endorsed by the OECD is exclusively prospective.

40. Using either an egalitarian social welfare function approach, or a Rawlsian analysis "behind the veil of ignorance" (Rawls 1971) leads to the rejection of the "polluter pays principle." Since at the time the relevant actions are taken, the polluter is not cognizant of the effects, such fees have no incentive effects, but rather appear as random taxes, lowering each person's expected utility, and in particular the expected utility of the worst-off individual.

There is a further ethical issue: ascertaining who the true beneficiary of escaping paying for the pollution is generally difficult. It need not be the individual, firm, or country actually engaging in the externality generating activity; in competitive markets, when firms are not charged the full social costs of production, product prices will fall, giving consumers a substantial fraction of the benefits.

41. Manne and Richels (1992) show that, under the IPCC emissions scenarios, even the most drastic controls on emissions from developed countries would be insufficient to stabilize greenhouse concentrations without some means of controlling emissions from developing countries.

42. Public goods exist when property rights are not or cannot be clearly assigned. The atmosphere is an international public good because assigning property rights to the atmosphere is difficult for one nation acting alone, and particularly difficult when many sovereign states must agree among themselves. Tradable greenhouse emission permits, discussed below, attempt to resolve the problem by explicitly assigning property rights to greenhouse emissions.

43. See Abreu [].

44. In some cases, equity considerations may prevent Coase (1960), in his discussion of externalities, emphasized the separability between efficiency and equity issues. Though there have been several important qualifications to Coase's conjecture, emphasizing the importance of public goods, imperfect information, and transaction costs (see Farrell , Stiglitz [1988]), still, the basic insight remains applicable here.

45. Chapter 7 discusses this issue at greater length.

46. These concerns are not just theoretical possibilities, as the following two examples illustrate. Assume that the North imposes high energy taxes, but the South fails to do so. Energy intensive industries, such as aluminum, migrate from North to South. But energy efficiency in the south is much less than in the north, so that the total energy used to produce a ton of aluminum could increase substantially. While economic efficiency would call for locating energy intensive industries where energy efficiency is greatest, a system of partial controls would result in energy intensive industries being located where energy efficiency is lowest. Similarly, the reduced energy consumption by the North will result in lower *producer* prices of oil and gas, leading to increased consumption of energy in the South, partially offsetting any energy conservation induced in the North.

47. The precise manner in which this should be done is a relatively technical matter. To the extent that there are large differences in atmospheric lifetimes, then the relative weighting of different greenhouse gases should change over time, since the "shadow price" associated with effects on relative concentrations at different dates will differ.

48. Similarly, if the developed countries restrict forest cutting, the price of lumber may rise, inducing the developing countries to cut down more of their own trees. While total carbon sequestration may not increase, environmental and economic efficiency will decrease if, as some researchers have concluded, hardwood forests

1 in the less developed countries may be the least desirable ones to cut down from an ecological or economic
2 perspective (Edmonds and Reilly, 1983).

3 49. Only a few models take into account international capital flows. Thus, most models do not address issues
4 of industry relocation (McKibben and Wilcoxon, 1992).

5 50. In the case of production of highly substitutable commodities, carbon leakage will, of course, be much
6 greater.

7 51. Whether taxes in fact have this effect depends in part on the shape of the demand curves. With
8 intertemporal separability in demand curves and constant elasticity, with no backstop technology, a constant ad
9 valorem tax has no effect on the pattern of consumption.

10
11 Coal presents markedly different issues, not so much because of its greater emissions per unit energy, but
12 because of its higher cost of extraction to price ratio. Lowering producer prices may result in less coal being
13 consumed, provided alternative energy sources become available. Thus, taxes on coal are likely to have
14 significant general equilibrium as well as partial equilibrium effects; the increase in the price of coal will lead
15 to a substitution of gas and oil. If alternative energy sources are not available, such policies will only affect the
16 intertemporal timing of coal consumption (given the much more limited resources of gas and oil). But even that
17 might be of some value in reducing long run greenhouse gas emissions, as the ability to extract energy from coal
18 may increase significantly over time. Analyzing the optimal intertemporal structure of taxes, to minimize long
19 run ambient levels of greenhouse gases, taking into account both intertemporal substitution and substitution
20 across energy sources, is a complicated technical issue, that to date has not been adequately analyzed.

21 52. United Nations Conference on Environment and Development, Framework Convention on Climate Change,
22 May 9, 1992.

23 53. The most difficult problem is posed by those investors who invested in these resources, on the basis of one
24 regime (where these resources were not taxed). Do they have any special claim to compensation for a "change
25 in regime." Changes in demands and supplies occur for virtually all resources, and are an inevitable part of the
26 risks in investing. While most economists would argue that arbitrary and capricious changes in policies
27 contribute to business uncertainty, and therefore have an adverse effect on economic growth, reasoned changes
28 in policies in response to changes in information are an inevitable part of the business risk.

29 54. For example, U.S.A. electric utilities are already making decisions in anticipation of some future policies to
30 limit greenhouse emissions.

31 55. The studies show a marked variation in GDP losses across models. For example, stabilizing emissions at
32 their 1990 levels is estimated to reduce U.S. GDP by .2% to .8% in the year 2010 - roughly a \$20 billion to \$80
33 billion loss for that year. Estimate of the costs of reducing emissions by 20% below 1990 levels in the year 2010
34 range from .9% to 1.7% of GDP.

35
36 These GDP losses occur when the carbon taxes lead to investments that are more expensive than those that
37 would take place in the absence of the taxes. The higher the carbon taxes, the greater the investment in price-
38 induced conservation and the more fuel switching toward the less carbon-intensive substitutes.

39
40 The overall impact of a carbon tax will depend not only on the size of the tax but also on the uses to which the
41 revenues are put. In the standard EMF scenarios, it was assumed that tax revenues will be redistributed in a
42 neutral manner (i.e., without affecting the marginal tax rates). There are, of course, numerous ways in which
43 tax revenues can be used. These include: reducing budget deficits; reducing marginal rates of income, payroll,
44 corporate or other taxes; granting tax incentives to preferred activities; or increasing the level of government
45 expenditures. The costs of the tax will vary widely depending on how the revenues are recycled.

1 56. Top-down models estimate that for developing countries there exist low-cost options to reduce emissions in
2 the near term, but eventually costs would exceed 1 to 2% of GDP (EMF 1993). For economies in transition,
3 because of historical inefficiencies and energy subsidies, there exist large opportunities to reduce emissions at
4 little or no cost. For developing countries, problems of informal economies make hard estimates difficult, but
5 the cost of stabilizing emissions would likely be large enough to cut into economic growth.

6 57. Recent comparisons indicate that the most important differences between top-down and bottom-up models
7 arise from differences in input parameters, rather than from differences in model structure.

8 58. Government institutions and regulations often hinder the efficient use of energy. The developing countries
9 are least able to absorb the costs of these inefficiencies. Thus, while some developing countries argue that they
10 cannot afford to reduce greenhouse emissions, the same countries have the most to gain from reforming
11 government-caused inefficiencies. At least in the short run, international agreements committing countries to
12 eliminate at least the most egregious of these practices might go a long way to addressing the problem of
13 emission reductions, .
14

15 59. *Full utilization of non-fossil fuel energy sources*, taking account of other environmental impacts.) For example,
16 when hydroelectric power generation, which does not increase greenhouse emissions, can be cost-effectively
17 expanded without other environmental effects, it should be done.

18
19 *Eliminating Regulations Impeding Efficient Energy Utilization.* Many, perhaps most, countries have a host of
20 regulations which increase energy use as they impede economic efficiency. For instance, the United States has
21 had a policy of restricting oil exports to Alaska. Whatever the merits of that policy, it has forced Japan to import
22 oil from Indonesia and Saudi Arabia. World oil transportation costs have thus been greatly increased, at the
23 expense of the American economy. Another example of government reform, included in the US' Action Plan
24 (1993), encourages efforts to expand and improve natural gas markets through continued regulatory reform.
25 These reform efforts include guidelines to allow greater natural gas use in the summer in coal- and oil- fired
26 power plants.
27

28 *Other regulation.* Unintended effects of many tax, expenditure and other policies have contributing further to
29 inefficiencies in land use. Among the unfortunate effects of the U.S. Superfund program for the management
30 of hazardous wastes has been the creation of large unoccupied holes in the center of major cities.

31 60. A country that rapidly depletes its natural resources may show a high rate of growth under conventional
32 income accounting, but a lower rate of growth when resource depletion is taken into account. Repetto (1991,
33 1992) calculated resource-adjusted GDP for several countries rapidly harvesting their stocks of hardwoods and
34 other resources, arguing that conventional measures sharply overstated GDP.

35 61. Cobb and Daley (1989) have even claimed that U.S. per capita GDP, when adjusted for environmental
36 damage, was stagnant between 1950 and 1986. This assertion is hard to reconcile with the steady improvement
37 in most measures of environmental quality since 1970, when measurements standards were established.

38 62. Analysts now use two methods to estimate stocks. The first assumes a fixed stock of a natural resources
39 such as oil. Consumption of oil then depletes the stock by the amount of consumption. The second begins by
40 treating discovered reserves as the asset. Thus, additions to reserves increase the asset, while consumption
41 reduces it. If in any given year, new discoveries match resource utilization, then according to this method no
42 net depletion has occurred.

63. Many researchers have noted deficiencies in standard national income accounts. First, national income accounts do not, in general, provide an adequate measure of welfare; second, they do not provide the correct information relevant for making policies relevant to sustainable development. Sustainable development is concerned with society's resources; an economy is growing when its resource base (capital stock combined with natural resources) is growing. GDP does not, and is not intended to be, a measure of resource availability. Firms have two sets of accounts--cash flow (income) statements and balance sheet statements. GDP is a statement of the former type.

Standard accounting procedures require that firms, in an attempt to present an accurate account of "true income," take account of depreciation. GDP measures gross output; it does not take into account depreciation, either of natural or physical capital stocks. The reason is simply that it is hard to get accurate measures of depreciation.

Net national product does take into account depreciation, the change in capital stock. And it is this account which should be most subject to criticism, since it accounts for changes in the physical capital stock, but not in other capital assets, in particular, environmental assets and natural resources.

A number of difficult conceptual problems face the analyst defining levels and changes in levels of these assets.

First, how should the "stock" of natural resources be defined? Coal poses perhaps the easiest situation. The location of coal reserves is known. Costs of extraction are high, so the rents (the value of coal *in situ*) is low. The depletion can be measured not by the coal used times the market price, but the coal used times the *in situ* value. But for oil and other minerals, information about where reserves are located is vital. Two models have been proposed. One sees the world as having a fixed stock of natural resources (say oil). When one uses oil, one is depleting this stock. Thus, to calculate the value of depletion, one does not need to know the entire stock; the flow (the amount of oil consumed) provides an accurate measure of the change in stock.

The alternative model looks at the size of discovered reserves. Reserves are treated as the asset. Additions to reserves thus are viewed as increasing the resource base. If in any given year, new discoveries match resource utilization, then there is no net depletion. This is the approach being taken by the U.S. Department of Commerce. This accounting framework would be correct if there were an infinite supply of the resource (reflected in zero rents); the essential "capital" good is information about where the resource is located.

Environmental assets--such as air quality--present another set of problems, because there are not market prices to value the asset. Dynamic optimization problems of the kind described earlier can be used to calculate shadow prices. How sensitive these shadow prices are to specific assumptions remains to be investigated.

Accounting systems do not, however, have to aggregate all information together. Just as information about longevity and other indicators of well being (see below) serve to complement information from national income accounts concerning standards of living, so too can information about *physical* environmental measures be used to complement information from the extended national income accounts.

64. Consider the following thought experiment: compare an optimally designed road system which only carried cars; and contrast that with an optimally design road system which also carries trucks. The incremental cost of carrying trucks is, in most countries, much larger than the proportionate share of the cost they bear in gasoline taxes and other fees.

65. For example, in many countries, governments have taken an active role in the dissemination of information to the agriculture sector. These programs are in some measure responsible for the large increase in agricultural productivity in countries with agricultural extension services.

66. This issue has been addressed in several papers. See, in particular, Stiglitz [1975, 1984] and Grossman [1981].

67. This is both because those who would, under "true" disclosure, be at a competitive disadvantage have an incentive to add "noise" and because there are strong market forces for product differentiation; in markets with homogeneous commodities, profits, even with a limited number of suppliers, will be driven to zero (in Bertrand competition.) For a discussion of these and related issues, see Salop [1977], Salop and Stiglitz [1977, 1982], Stiglitz [1977, 1988].

68. The standard reference in the organizational literature is March and Simon. Economic theories emphasizing the non-value maximizing behavior of managers include the works of Baumol [], Marris [], and Leibenstein []. The principal agent literature [Ross, 1973, Stiglitz, 1974] provided the informational micro-foundations for understanding the divergences of interests. See Stiglitz [1988]. A more recent overview is provided by Stiglitz [] and the symposium in the Journal of Economic Perspectives.

69. This key point, while noted in March and Simon's [1958] original work, was elaborated upon by Radner [] and Hannaway [].

70. The facts that time is a scarce commodity and that decision making in large organizations is decentralization do not in themselves constitute a market failure; they do not prove that resources are not efficiently allocated given the real constraints facing society, which include time. However, Greenwald and Stiglitz [1986, 1988] have established a very general theorem showing that when information is imperfect and costly, market equilibrium is, in general, not (constrained) Pareto efficient. Thus, there is no *presumption* concerning the efficiency of the market economy, even in the absence of the kinds of externality and public goods problems that are associated with greenhouse gases. For a more extended discussion, see Stiglitz [1994].

One of the main insights of recent advances in the economics of information is to provide a sound micro-foundations for these theories of the firm. And indeed, the importance of the limitations on the availability of information, and the consequent importance of attention directing efforts applies to individuals as well as to organizations. Some studies have suggested that the limited success of the special tax provisions in the United States designed to encourage savings (IRA accounts) was primarily due to the competitive efforts of banks to recruit these accounts, and the attention which savings got as a result.

71. Network externalities are manifested in other ways: builders fail to install energy efficient light bulbs, because customers dislike them, because stores do not carry replacements; and stores do not carry them because the demand for them is too low.

When there are important network externalities, market equilibria are frequently inefficient. The economy might, for instance, get "stuck" in the wrong equilibrium. Government action can, in these instances, "force" the economy to move from one equilibrium to another.

72. This is not the only explanation of differences between bottom-up and top-down models. There are several other features of market behavior that bottom-up models often ignore.

(a) *Hidden Costs*: Consumers value a range of attributes difficult to include in an engineering model. For

example, auto buyers value not only initial costs and fuel economy (which computer models can easily calculate), but also performance, safety, and durability, which they typically do not.

(b) *Divergence between laboratory and in-use performance*: Especially for new technologies, actual energy use often differs significantly from energy use calculated in the laboratory. It is the latter upon which purchasers focus.

(c) *Variation across individual consumers*: Engineering models generally assume an average consumer; actual consumers may display a wide range of characteristics and usage patterns. Except when demand functions are linear in the relevant variables, the consumption of the "average" individual is not equal to the average consumption; and what is optimal for the average person may not be optimal for a significant fraction for the population.

73. For a survey, see Jaffee and Stiglitz []. The basic theory of credit rationing was developed in Stiglitz and Weiss [1981] and the theory of credit rationing is developed in Greenwald, Stiglitz, and Weiss [1984] and Myers and Maljuf [1984].

74. This generally accepted methodology is, for instance, reflected in the guidelines issued by the Office of Management and Budget in the United States for the evaluation of projects and regulations. The applied literature does not address the question of whether this procedure is appropriate in the presence of certain types of time and risk non-separabilities.

75. Though if the variance of the net benefits is increasing over time in a particular manner, the differences in the two methodologies may not be large.

76. Again, under certain restrictive conditions, where the shadow value of a capital constraint is changing systematically over time, the differences in the two methodologies may not be great.

77. See Wilson . Though the original discussion of winners curse focused around bidding in auctions, it has subsequently come to be applied to a range of other market phenomena. See, e.g. Stiglitz [].

78. For a discussion of the role of the state in capital markets, see Stiglitz [1994].

79. In some industrialized countries, energy efficient home mortgage lending may help correct the problem. Lenders generally set criteria for the maximum loan amount based on the borrowers' ability to repay, which in turn depends on income and wealth. The fact that a particular expenditure which would enhance efficiency and reduce utility bills is not given special attention. Energy efficient mortgages provide funds to households to make energy efficiency enhancing investments intended to pay for themselves, i.e. result in reduced utility bills equal to or greater than the interest payments. With capital constraints, builders may have an incentive to trade off initial capital costs for higher maintenance costs (lower energy efficiency). Building codes specifying minimal levels of energy efficiency and full disclosure of expected life cycle energy costs may help address these market distortions.

80. There is some concern that excessively broad and long patents may actually impede innovation. When technological progress occurs by building on previous innovations, later innovator require permission of earlier innovators to realize the returns on their innovation. While advocates of broad patent coverage argue that the parties always arrive at efficient bargaining solutions, critics point out that the outcomes of bargaining models with incomplete information often entail large inefficiencies.

81. Matters are more complicated, since the patent does not reward the innovator with his marginal contribution - the increase in the present discounted value of benefits as a result of the innovation occurring earlier than it otherwise would have occurred. For a fuller discussion, see Stiglitz [1994], Dasgupta and Stiglitz [1980a, 1980b], Barzel [].

82. If less developed countries fail to implement fully a set of corrective taxes or tradeable permits, or if less developed countries fail to adopt and enforce effectively intellectual property rights, there will be insufficient incentives to produce energy and emission savings innovations, particularly those appropriate for the level of technological knowledge, human capital, and factor prices in those countries. If less developed countries do take these actions, there is concern that they will result in higher prices of innovations, and thus the pace of adoption will be retarded. An effective form of aid, targeted to reducing greenhouse gas emissions, may be subsidies directed at producing appropriate energy saving and emission reducing technologies for LDCs.

83. Edmonds *et al.* (1994) has studied the importance of available advanced energy technologies such as those proposed by Johannsen (1993). Edmonds *et al.* use the Edmonds-Reilly-Barnes model for energy related greenhouse gas emissions; the MAGICC model for atmospheric composition, climate response, and sea level rise; the IPCC scenario IS92a (IPCC, 1992) as the reference base case and five alternate energy scenarios that are far more advanced over today's energy supply and transformation technologies. The five energy scenarios are:

- a. advanced fossil fuel technologies
- b. advanced liquified hydrogen fuel cells
- c. advanced hydrogen fuel cells without liquified hydrogen
- d. low cost biomass
- e. accelerated rate of exogenous end-use energy intensity improvement

Combined, the energy technologies reduce annual emissions from fossil fuel use to levels that stabilize atmospheric concentrations below 550 ppmv (i.e. double the concentration prior to the Industrial Revolution). The tax rate, assumed to apply globally, used was the marginal cost of stabilizing fossil fuel carbon emissions in the reference case. With values reflected for only carbon dioxide emission reductions, the cost of global emission reductions grow from approximately \$35 (US) Billion in 2005 to \$230 (US) billion per year in the year 2095. With advanced fossil fuels, low cost solar electric power, low cost fuel cell vehicles, the present discounted value of adding low cost biomass fuel to the energy technology bundle is almost half a trillion dollars (US). The present discounted value of the advanced energy technologies taken together is \$1.8 trillion (US).

The introduction of advanced biomass energy production technology was found to play a key role in reducing emissions. Biomass energy at \$2.00/GJ growing to become the core energy supply technology by 2050 could significantly reduce emissions highlighting the potential role of technology development and deployment relative to that of fiscal and regulatory intervention.

These results should be viewed as illustrative rather than predictive. In this analysis, the gains from introduction and deployment of advanced energy technologies is dependent on the order of technologies evaluated in the study.

84. The literature has identified three types of permit systems. The ambient permit system (APS) works on the basis of permits defined according to exposure at the receptor points. Each polluter, then, may face quite complex markets - different permit markets according to different receptor points, and hence different prices. The simpler emissions permit system (EPS) issues permits on the basis of source emissions and ignores what effects those emissions have on the receptor points. Within a given region or zone, the polluter would have only

one market to deal with and one price. Finally, there is the pollution offset (PO) system wherein the permits are defined in terms of emissions, trade takes place within a defined zone. However, the standard has to be met at all receptor points. The exchange value of the permits is then determined by the effects of the pollutants at the receptor points. The PO system thus combines characteristics of the EPS and the APS. (Pearce and Turner 1990) These distinctions are of limited relevance for greenhouse gases, where what is of concern is global emission levels. The specific location of the emissions is of no concern.

85. The choice between taxes and tradeable permits depends on the objectives of the policy maker and nature of the uncertainty about the marginal cost and marginal benefit curves for carbon emission reductions (Weitzman, 1974). Theory tells us that if the nature of the curves is known with very little certainty, but the marginal cost curve is known to be relatively steeper (i.e. a change in the level of pollution allowed brings about a greater change in the marginal costs of mitigation compared to the marginal benefits) then taxes should be the policy of choice. This is because, in this case, an erroneous estimation of the optimal tax rate will lead to a relatively small deviation from the optimal pollution level. On the other hand, an erroneous estimation of the optimal level of total emissions in a permit scheme will lead to a relatively large deviation from the optimal cost of the permits.

If the marginal benefit curve is known to be relatively steeper than the marginal cost curve, however, tradable permits are the better option. Here, an erroneous estimation of the optimal tax rate will lead to a relatively large deviation from the optimal level of emissions while an erroneous estimation of the optimal level of emissions in a permit strategy will lead to a relatively small deviation from the optimal cost of the permits.

In the case of greenhouse gas emissions, the time horizon for adjustment is sufficiently long that many of these uncertainties become less important. If the tax rate initially chosen yields too high a level of emissions in one year, it can be increased, and the net impact of the erroneous initial estimate on global warming (or the total cost of achieving a given level of atmospheric concentration) will be negligible. In any case, as the earlier discussion on sequential decision making has emphasized, there is likely to have to be continued revisions in either tax rates or permit levels.

Still, there is some argument that the required adjustments under a permit scheme may be less burdensome. (Tietenberg 1992) For instance, if the authority feels that the old standard needs some tightening they may enter the market themselves and buy some of the permits, holding them out of the market.

There must be effective, competitive markets in tradeable permits, if such schemes are to achieve efficient outcomes. There are transactions costs of running such schemes, just as there are transactions costs associated with collecting tax revenues. Whether transactions costs gives one system a decided advantage over the other is not clear. There seems to be no compelling reason to believe that good markets in tradeable permits would not develop.

86. It is possible to design allocations of trading permits which (i) on average, impose no net burden on developing countries (thus conforming to the ability to pay principle); (ii) provide those economies which are growing faster per capita with commensurately greater permits, thus imposing no net drag on economic growth, provided the economy exhibits an increase in fuel efficiency at least equal to the average of fast growing LDCs; and (iii) rewards those economies which are able to reduce greenhouse gas emissions faster than benchmark, either through greater control of population growth, through larger increases in energy efficiency, or through switching from higher to lower carbon fuels.

The extent to which individual circumstances of countries should be taken into account in setting benchmarks

remains a question for international negotiations; to the extent that high emissions is due to natural endowments (e.g. the availability of coal rather than natural gas as a source of energy), a persuasive case can be made for benchmarks to reflect initial emission levels. To the extent that high emissions are due to inappropriate energy pricing policies, the case that benchmarks should reflect initial emission levels is far more tenuous.

87. Similarly, some developing countries have asked, should the North be given higher levels of permits, simply because it has, in the past, been the chief source of greenhouse gases?

88. For a discussion of the polluter pays principle, see above.

89. Standard tradeable permit schemes essentially take the revenue from a carbon tax, and distributes it to current user emitters, rather than using the revenue to reduce other taxes. An alternative to these standard schemes is for the government to auction off the tradeable permits.

If taxing carbon leads to reduced labor supply or reduced savings, then government revenues from wage or capital taxes may be reduced, more than offsetting the direct revenue gain from the carbon tax. Cross elasticities of this magnitude are unlikely, though any such cross elasticity will reduce the net gain from the carbon tax. The magnitude of the double dividend has been the subject of some dispute, with Goulder [] and taking opposite views.

90. Two main studies provide insights into the root of the variance in estimates of the economic effects of carbon taxes: The Energy Modeling Forum Study (12) and the OECD comparison project. In each case, sophisticated sensitivity analyses are run by standardizing key economic assumptions along with use of common reference case scenarios of reductions. The magnitude of the effect on economic growth will depend both on assumptions concerning the effect of carbon taxes on savings and labor supply, and the induced investment to offset the higher energy prices. If higher energy prices do not lead to much capital substitution and if the cross elasticity with savings and labor are low then the likely effect on economic growth will be small.

OECD Project on Economy-Wide Cost Estimates of Carbon Taxes:

An OECD model comparisons project was conducted to compare economy wide estimates of the effects of carbon taxes. Time horizons as well as the key economic assumptions on growth, population and resource prices, and the reduction scenarios for six global models were standardized. The global models compared were the GREEN model, the IEA model and four North American models [Edmonds-Reilly Model (ERM), Global 2100 of Alan Manne and Rich Richels (MR), the Carbon Rights Trade Model (CRTM) of Tom Rutherford, and the Whalley-Wigle model] (Dean 1994).

There is significant variation in tax rates and costs for the same amount of emissions reduction among models due to differing assumptions regarding several key considerations. Several factors explain the differences between model results. The most important factors are:

- a. The degree of substitution between fuels - the ease with which producers and consumers can switch from high-carbon content fuels to low-carbon content fuels;
- b. Expectations about future energy prices and taxes;
- c. The speed of emissions reduction;
- d. The way in which revenue is recycled;
- e. The treatment of the removal of energy subsidies; and
- f. Assumptions regarding backstop technology and a host of other technical and economic factors.

Because of the varying approach to these questions, the range of estimated tax rates and costs are quite wide. For a 45% reduction in baseline emissions by 2020, the required tax would be in the range of \$150-\$325 per ton

1 of carbon and the cost might be in the range of 1.5%-2.9% of world GDP. A 70% reduction in baseline
2 emissions by 2050 could require a tax between \$230 and \$880 and a loss in world GDP of 2.4%-3.8% (Dean
3 1994).

4
5 The required carbon taxes and associated costs vary significantly across regions in all of the models. This
6 indicates that the same proportional reductions in emissions across all regions would give rise to very different
7 costs in different regions and would thus be globally inefficient - with great potential for savings in the global
8 cost of reducing emissions through the use of emission trading between countries or regions (see section 1.5.2.1)
9 or a global carbon tax.

10
11 Three insights emerging from the OECD study are (Dean, 1994):

- 12 a. Small amounts of emissions reduction can probably be achieved with low taxes;
- 13 b. Large reductions can only be achieved at high tax rates (i.e. marginal reduction costs rise with emissions
14 reductions).
- 15 c. Carbon-free backstop technologies are likely to slow the rise of the carbon tax, or halt it altogether, if they
16 are available at constant marginal cost.

17
18 *Energy Modeling Forum Project 12 (Impact of Carbon Emission Control Strategies)*

19 A recent study at Stanford, the Energy Modelling Forum Project - 12, examines the cost of reducing CO2
20 emissions (Energy Modeling Forum, 1993). A diverse group of economic models, employing common
21 assumptions for selected numerical inputs, were used to analyze a standardized set of emission reduction
22 scenarios. In all, 14 top-down models participated in the study.

23
24 The EMF model comparison provides the most comprehensive application of top-down methodologies to date.
25 The study addresses a wide range of policy questions. How large are emissions likely to grow in the absence
26 of controls? How much market intervention will be required to meet alternative targets? What will be the price
27 tag? In exploring economic costs, the modelers were asked to examine the impacts of timing, research and
28 development, and revenue recycling.

29
30 The EMF exercise provides a wealth of useful information for policy making. Although the focus was primarily
31 on the U.S., many of the insights are applicable to developed countries in general.

32
33 In selecting parameters for standardization, the EMF study focused on what were felt to be the most influential
34 determinants of mitigation costs. These included: GDP, population, the fossil-fuel resource base, and the cost
35 and availability of long-term supply options. In addition, although the EMF models differed considerably in their
36 technology representation, the study attempted to impose uniformity with regard to world oil prices, the oil and
37 gas resource base, and the cost of backstop technologies. For its reference case, EMF adopted the average of
38 the IPCC high and low economic growth cases (IPCC, 1990c). Also for consistency with the IPCC, the study
39 adopted the population growth projections based on Zachariah and Vu.

40
41 The modelers generally used taxes based on the carbon content of the fossil fuels in order to achieve a
42 prescribed emissions reduction. The magnitude of the tax provides a rough estimate of the degree of market
43 intervention that would be required to achieve the carbon emissions target. Estimates range from \$20 to \$140
44 per ton for the carbon taxes required to hold emissions at 1990 levels in 2010. Estimates of the carbon taxes
45 required to reduce emissions by 20% below 1990 levels in 2010 range from \$50 to \$330 per ton.

46
47 Two parameters are particularly important in explaining the differences in tax projections: the price elasticity
48 of energy demand and the speed with which the capital stock adjusts to higher energy prices. Neither were
49 controlled in the EMF experiments. Those models using lower price elasticities required higher taxes to achieve
50 the same emissions goal. Those models which assumed greater malleability of capital required lower taxes.
51

1 91. Rapid capital stock retirement may add to the cost of immediate CO2 reductions. Also, reductions may be
2 cheaper later because of technical changes in the intervening years.

3 92. Indeed, the "ratchet effect," a commonly observed phenomena in the command and control economies
4 (Stiglitz, 1975, Weitzman, 19) leads firms to just satisfy the target.

5 93. Two examples from the United States Clean Air Act: 1) the requirement that coal-burning power plants
6 install stack-gas scrubbers even if they burn low-sulfur Western coal; 2) the mandates for ethanol in reformulated
7 gasoline.

8 94. World Commission on Environment and Development, Our Common Future, Oxford: Oxford University
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10 95. Other views represented in the debate on sustainable development but not generally accepted in the
11 economics profession include those of Daly (1977, 1980) and Daly and Cobb (1991), and those of the new field
12 of ecological economics (Costanza 1991).

13 96. Tariq Osman Hyder, "Climate Negotiations: the North/South Perspective," in Mintzer, ed. Hyder has headed
14 the Pakistani delegation at meetings of the INC, and GEF (Global Environment Facility).

15 97. "Principles of the G-77 and China on the Climate Convention," cited in Tariq Osman Hyder, "Climate
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6

TO: Joe Stiglitz

FROM: Ray Squitieri

1/13/95

SUBJECT: Discounting Chapter

The chapter is mostly cleaned up. It will certainly cause a stir with Bill Cline and others. Before it goes to them, however, please look at the questions **marked in bold print**. Some of these issues were raised by the peer reviewers, some by Randy Lyons of OMB, and some by me. Give me a call when you want to talk. This should go out by 1/20.

Chapter 3

Intertemporal Equity and Efficiency

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3.1 Introduction

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

3.1.1 Importance of the Discount Rate

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

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

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

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

Social scientists have debated the precise rate to use for global climate analysis (Broome, 1992; Cline, 1992; Nordhaus, 1993). There is general agreement that the choice of the discount rate has extremely powerful effects on the economic evaluation of policy on global warming because of the unusually long time horizons involved (e.g. Schmalensee, 1993). With benefits of greenhouse abatement accruing decades or even centuries into the future, if a high discount rate is used, the benefits get heavily discounted relative to the expenditures incurred today in trying to mitigate climate change.

For example, rates of 8% - 10% per annum are often used in project analysis. Such rates cause the future to vanish rapidly. Thus, discounting at 8%, damage of \$1 billion 50 years from now is valued at only

1 $[\$1 \times 10^9] / [1.08^{50}] = \$21.3$ million; and the same damage 200 years from now, at only \$200. This collapse of
2 future values suggests the need to think especially carefully about proper discounting for global warming
3 analysis.

4 5 3.1.2 Toward an Emerging Consensus

6
7 The framework of an emerging consensus on discounting for global warming analysis would include the
8 following.

9
10 First, although economists have disagreed about (a) whether future generations at levels of welfare or utility
11 equal to those of today should nonetheless be discounted relative to the present, and (b) how precisely to
12 relate changes in the discount factor to changes in income, there is widespread (but not universal) agreement
13 about the following propositions:

14
15 (i) Rejection of environmentally specific egalitarianism: future generations can be compensated for
16 some environmental/natural resource effects by offsetting accumulations of capital.

17
18 (ii) Acceptance of more generalized (but not, usually, absolute) egalitarianism: differences in the
19 overall standard of living should be reflected in the discount rate. There is, in fact, remarkable
20 consensus in the quantitative magnitudes by which future discounting should be affected by rising per
21 capita income. Given the best available forecasts, expected increases in the standard of living should
22 cause discounting on the order of 1/2 to 3 percent annually. ***** JOE: This range falls out of a
23 particular formulation. It may not be as widely accepted as the statement implies. *****

24
25 Second, trade-offs across generations are related to observed market rates of interest, although indirectly,
26 through the effect of market rates on the value of foregone investment alternatives.

27
28 Third, trade-offs across generations in environmental goods (or public goods) need not correspond to
29 trade-offs across generations in private consumption goods. Economists have developed a standard
30 operational procedure for dealing with this problem: converting other goods into their equivalent in private
31 consumption goods, and applying the discount rate to the equivalents. As discussed below, this procedure
32 will imply lower effective discount rates for environmental goods than for private consumption goods if
33 relative prices of environmental goods are rising ***** JOE: Doesn't this effect get reflected in the benefits
34 rather than the discount rate? *****. The same procedure also incorporates market rates of return, by
35 including as a cost of a project the foregone benefits of possible investments not undertaken.

36
37 Fourth, issues of discounting involve the relative values of goods at different dates, and thus intertemporal
38 pricing. Issues of pricing of risk need to be carefully separated out from those involving intertemporal
39 pricing. The standard procedure for conventional models, involving impacts over a single individual's life,
40 involves converting probabilistic consumption patterns into their certainty equivalents, and then discounting at
41 the social rate of time preference -- not the incorporation of an incremental component into the discount
42 rate itself. This procedure does not, however, deal adequately with uncertainties about future rates of growth
43 of per capita income. Such uncertainties are much greater over centuries-scale horizons. Under plausible
44 conditions, uncertainties about future rates of growth of per capita incomes should be reflected in a lower
45 discount rate ***** JOE: The uncertainties in the growth rate would seem to warrant a conservative or at
46 least equivalent discount rate. Once this is done, there is no need to further lower the discount rate, right?
47 *** Note that although the real concern is welfare or utility, analysts generally formulate the problem in
48 terms of consumption.**

49
50 Fifth, issues of equity can be treated in a way analogous to those of risk, though the likely effect on the
51 appropriate rate of discount have yet to be thoroughly studied.

3.2 Intergenerational Equity

Climate policy raises particular questions of equity among generations, because future generations are not able to influence directly the policies being chosen today that will affect their well-being (Mishan, 1975; Broome, 1992), and because it might not be possible to compensate future generations for reductions in well-being that might be caused by current policies. Because climate change policy involves trading off near term costs (e.g. of emission controls) for long-term benefits of a reduced rate of warming, issues of intergenerational equity cannot be ignored.

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

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

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. 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.

The Rawlsian max-min principle is the strongest in assuring future generations' rights to consumption at least as great as that of the current generation. *** JOE: should this say, "... strongest in assuring the least fortunate groups of future generations rights to consumption at least as great as that of members of the current generation." Or "... the least well-off generation in the future, considering the welfare of the average citizen in each. I am confused about which minimum you are referring to. *** 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. For intertemporal planning, in the absence of technical change this would imply that consumption per head should be the same for all generations. By contrast, the utilitarian criterion allows, in principle, future consumption to fall below current consumption, provided the current generation is made sufficiently better off as a result. Correspondingly, it also allows for decreases in present consumption, provided the future generation is made sufficiently better off as a result.

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

The individualistic social welfare function, accepted by most economists as the basis of ethical judgments, accepts individuals' own relative valuations of different goods.

It does not place separate valuations on unequal access to particular goods, other than through their effects on the affected individuals. Although this represents the consensus view, there are some economists who insist 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. *** Joe: new sentence: *** Similarly, Thurow (date) argued that income distribution is a public good.

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" (p. 349). *** Joe: Should this paragraph mention opposing views? It seems every effort has been made to feature the egalitarian case, with little attention to views of, say, the market-oriented or limited-government school. ***

3.3 Discounting and the Social Rate of Time Preference

The approach described in this section is sometimes called the prescriptive approach. It asks whether a particular program would make society better off, given a plausible social welfare function. The discounting rules specify how consumption at different dates should be valued to provide the correct answer to that question. The alternative view, described in Section 3.4, focuses on intertemporal efficiency and opportunity costs. To distinguish it from the prescriptive approach, it is sometimes referred to as the descriptive approach.

Investments in both physical capital (e.g. machines) and human capital (e.g. education) yield on average a

A Dissenting View on Discounting

At least one prominent economist explicitly rejects the framework presented here. Schelling (1994) refutes the approach of deriving the discount rate from a model that maximizes the marginal utility of consumption over time, arguing that this approach requires the maximization of utility for a single representative individual who lives forever (or perhaps a constant population of individuals with identical utility functions). The essence of climate change, on the other hand, is different consumers facing different consumption choices at different times. Hence, the focus must be on utility effects of income transfers between agents rather than maximizing utility for a single agent.

Schelling notes that most of the costs of climate change programs are likely to be paid by the OECD countries, while most of the benefits will accrue to the developing countries, which will represent 90% of the world's population by the middle of the next century. Thus, he says, these projects should be looked at as a variety of foreign aid. Once we abandon the standard cost-benefit approach, the resources to be devoted to climate change mitigation become a matter of choice, not an analytical result.

positive real return. That is, money invested today can be transformed into more money later, even after adjusting for inflation. Discounting converts each future dollar amount associated with the project into the equivalent present dollar amount that must be invested today in the general economy in order to yield the same future amount.

Greenhouse gas emission control may be viewed as an investment: money is spent today on emission controls today so that more money (or other benefits) may be received later in the form of reduced economic costs of global warming. If the real rate of return on investment in emission reduction exceeds the rate on investment in machines and education, then future generations would be better off if less were invested today in machines and education and more in controlling greenhouse gas emissions; the converse also holds.

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

1. Total impacts on consumption (or welfare) across generations: the social rate of time preference, a reflection of societal views concerning trade-offs of consumption across generations, should be employed.
2. Direct costs and benefits of a greenhouse mitigation project: Suppose that a mitigation project would displace private investment, and that returns to both projects accrue to the same generations. Then it is appropriate to use the opportunity cost of capital - the private return - in discounting.
3. Competing investments: The cost of a greenhouse mitigation project must include the foregone benefits of other competing investments not undertaken. Only then will it be appropriate to use the social rate of time preference.
4. Evaluating environmental goods: the effective rate of discount need not be the same for environmental goods as for private goods. Under plausible assumptions, the incorporation of environmental considerations may have consequences equivalent to those of adopting a lower discount rate. ***** JOE: Doesn't this confuse valuation with discounting? *****

3.3.1 Formulation of Prescriptive Approach

The first issue in the analysis of the discount rate is the question of how we value consumption accruing to different generations. Within the predominant utilitarian (as opposed to Rawlsian) framework, there is relatively wide agreement ***** citation needed for the claim of relatively wide agreement ***** on the form of the fundamental equation for the discount rate of consumption, or the "social rate of time preference" (SRTP):

$$3.1) \text{ SRTP} = \rho + \theta g$$

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

The first term (ρ) is the rate at which utility is discounted because it occurs later rather than sooner. Sometimes this term, the rate of pure time preference, is referred to as discounting for impatience or myopia. The second term (θg) is the rate at which changes in consumption levels are discounted to be translated into the resulting changes in utility or welfare levels. The idea is that if per capita consumption is

growing a rate g , then an extra unit of consumption in the future should be discounted by the term θg to take account of the lesser increment to utility when consumption levels are higher.

Annex 3A sets out the mathematics of discounting. Along an optimal path, the marginal product of capital (equal to the market rate of interest) and the discount rate on consumption both equal $\rho + \theta g$. It is important to emphasize that in using the SRTP approach, we value the total change in consumption at each date, not just the direct outputs of the project. *If the project displaces private investment* that has a high marginal productivity, then there will be a large loss in output and consumption resulting from the displacement. The prescriptive view takes into account *opportunity costs in calculating changes in consumption*, but in valuing the changes in consumption, uses the SRTP.

3.3.2 The Pure Rate of Time Preference Across Generations

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

For an individual, some non-zero value of pure time preference can make sense, because he or she has a finite life and thus uncertainty about being alive to enjoy future consumption. Nonetheless, for a life span of some 70 years, pure time preference at even 1 percent per annum implies willingness to accept consumption levels only half as high at the end of the life cycle as 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, because society's life span is measured in at least millennia rather than decades. Nonetheless, arguments have been put forward contrary to the notion of zero pure time preference across generations, and instead supporting the conclusion that future generations should have less standing than current generations.

3.3.3 Discounting Utility for Human Extinction

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

Thus, according to some estimates the probability that an individual will die because an asteroid hits the earth during his or her lifespan is about one in ten thousand, in the same order of magnitude as the probability that he or she will die in an airplane crash. ***** JOE: These calculations suggest that asteroid impacts may be a larger risk than climate change, particularly if the SWF includes risk aversion. I know that contributors to this report would object to this conclusion, but it is suggested by the risk estimates in this paragraph, and careful readers will draw the conclusion. ***** 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).

1 However, to be generous to the extinction argument and for purposes of illustration, consider the individual
2 risk at one in 10,000. The three-century horizon appropriate for global warming analysis is about four life
3 spans, so set the probability of asteroid impact over this period at $1/2,500$, for purposes of illustration. Then
4 at the end of this period, a given economic effect should be discounted enough to shrink its value by one-
5 2,500th. The discount rate required for this shrinkage is vanishingly small ($= 0.133 \times 10^{-4}$ percent per
6 annum).

7
8 Perhaps one reason the optimal growth literature includes discounting for extinction is that most of the
9 literature emerged during the cold war, when nuclear annihilation was more plausible than today. For public
10 policy purposes, even under those conditions it is arguably inappropriate to incorporate analytical
11 assumptions that take as a premise the failure of policy (breakdown into nuclear war). In any event this
12 motive for extinction-based discounting would seem even less appropriate for the future.

13 14 3.3.4 Discounting Utility for Acceptable Optimization Results

15
16 Another argument for non-zero pure time preference is that setting the rate at zero could imply that the
17 present generation should accept near-starvation consumption levels, and correspondingly low utility, because
18 with even very small returns on investment, an endless stream of future generations could enjoy increased
19 consumption and (to a lesser degree) utility as a result. Koopmans (1965) thus emphasized the importance of
20 considering the acceptability of optimization outcomes as an additional step going beyond the Ramsey
21 first-principles approach.

22
23 To some extent, however, this concern is already addressed in the overall discount rate equation (3.1). As
24 noted, the first term in that equation discounts utility (pure time preference), but the second term
25 additionally discounts consumption to take account of falling marginal utility. The present generation can be
26 protected against an optimizing program setting its consumption near zero by ensuring that the term for
27 elasticity of marginal utility (θ) is large enough and marginal utility drops off fast enough to rule out
28 impoverishment of the present generation for gains to future generations.

29
30 More fundamentally, a basic problem with this genre of concern about zero pure time preference has to do
31 with the mathematics of maximization over an infinite time horizon. If the utility function has no upper
32 limit, any savings-investment optimization problem is not well defined, because the sum of utilities over time
33 is infinite. There is some literature (Weizsacker 1965) proposing criteria (the "overtaking criterion") to
34 address this problem, but the implications of these criteria for climate policy have not been examined.

35
36 Even when the optimization problem is made well-defined, for the purposes here, by setting an upper bound
37 to utility (as in the function in annex equation 3A.3), there is a tendency toward knife-edge results, with one
38 extreme outcome for zero pure time preference and the opposite extreme for non-zero rates. Thus,
39 whereas the concern of Koopmans (1965), Mirlees (1974), and Chakravarty (1969) is that zero pure time
40 preference can suppress current consumption to unacceptably low levels, just the opposite result can be
41 reached in optimization models that take exhaustible resources into account. In some specifications of such
42 models (Dasgupta and Heal, 1974; Solow, 1974a), any pure time preference rate in excess of zero generates
43 the unacceptable result that optimal consumption falls to zero over the very-long term (although Stiglitz,
44 1974, shows that this awkward conclusion is not robust with respect to alternative assumptions about
45 technological change, production functions, and utility functions).

46
47 Knife-edge results can of course result from other properties of utility maximization models as well
48 (depending, for example, on whether the production function has non-unitary elasticity of substitution
49 between factors, or whether capital-augmenting technical change is zero or positive). Because of the
50 mathematical and knife-edge complications of optimization approaches, they do not go far toward specifying
51 the proper magnitude for the rate of pure time preference, even though they might be seen as providing a
52 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 future generations, depending on other assumptions of the model.

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

3.3.5 Discounting Utility for Empathic Distance

Rothenberg (1993) and Schelling (1993) have suggested that although non-zero pure time preference might make sense for an initial two or three decades, beyond a certain future point it makes no sense to apply further discounting of consumption for pure time preference. Thus: "as the future recedes... single generations come to be perceived more and more as homogeneous entities (Rothenberg). Similarly: "time may serve as a kind of measure of distance....Beyond certain distances there may be no further depreciation for time, culture, geography, race, or kinship" (Schelling). A graph of the fraction of face value accorded to each successive generation (for constant real consumption) would thus be a series of declining, successively shallower steps that eventually reach a horizontal plateau. A deep plateau signifies major discounting for empathic distance; a horizontal line beginning and remaining at unity is the zero pure time preference rate across generations recommended by Ramsey. Policy based on empathetic distance (a shelf lower than unity) may be more defensible in a normative sense when the action is refraining from conferring a windfall gain (as in penurious aid budgets) than when it involves the imposition of windfall damage (as in global warming's effects on future generations).

3.3.6 Discounting for Rising Levels of Consumption and Utility

Even if future generations are given weight equal to that for current generations, so that pure time preference (ρ) is zero, there could still be an important basis for discounting future consumption: people are expected to be better off, so that an extra unit of consumption would not be worth as much in the future as today. Thus, if technological change continues to proceed at the rate at which it has over the last century, with productivity and living standards doubling every thirty years or so, then marginal changes in consumption of those future generations should be weighed much less. This consideration is captured by the second right-hand term in equation 3.1.

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

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

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

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

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

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

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

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

In general, the market rate of interest--the relative price of consumption of one generation in one year of its life to consumption in another year--will not equal the SRTP. In standard life cycle models, even with no technological progress and an economy in steady state, there would be no discounting for society's purposes

1 ***** Is this sentence clear? *****. Nonetheless, the market rate of interest will be positive in any efficient
2 equilibrium under certain reasonable assumptions about utility functions (such as individual impatience and
3 zero bequest motive; Diamond, 1965). In such models the market rate of interest would thus always
4 overestimate the SRTP. Under some special conditions, with governments intervening with non-distortionary
5 taxation to optimally redistribute income across generations, then observed market rates of interest will
6 accord with the SRTP. But these are highly specialized conditions. (See Stiglitz, 1985, Pestreau, 1972). The
7 market rate of interest will, however, enter into discounting calculations even using the prescriptive approach.

8 9 3.3.8 Discount Rate Estimates -- Prescriptive Approach

10
11 The approach described in the previous sections, under plausible assumptions, leads to low discount rates for
12 changes in consumption of future generations. With high rates of productivity increase (and high g), of the
13 order of 1.5%, and high values of the elasticity of marginal utility (θ), the social discount rate is of the order
14 of 3%; with low rates of productivity increase, of the order of .5%, and low values of the elasticity of
15 marginal utility, the social discount rate is of the order of .5%.

16
17 It must be emphasized that these discount rates apply to consumption only, and that they can be applied
18 only after the foregone benefits of other investments have been included in the costs of the program.

19
20 In general, there is no reason why the discount rate should be constant over time even if ρ and θ are
21 constant, since g need not be constant. In fact, if we assume a gloomy scenario where future output and
22 consumption decline, then g and thus the SRTP may be negative (Munasinghe, 1993).

23
24 Developing countries, with higher rates of productivity increase, can justify higher rates of discount, at least
25 until the gap between their standards of living and those of the more developed countries have been closed.
26 With labor productivity increases and per capita income growth of the order experienced by the Asian
27 miracle countries of 5 to 8% per year, and elasticities of marginal utility of 2, discount rates of the order of
28 10% to 16% could be justified. Similarly, low-income countries close to subsistence levels could have high
29 elasticities of marginal utility (rapid dropoff of marginal utility from initially extremely high levels associated
30 with privation), so that their SRTPs could be high even if they were experiencing slow growth over long
31 periods. These distinctions have important implications for global warming policy, because they would tend
32 to mean that the calculus of trading off present abatement costs against future benefits from avoidance of
33 global warming damage could be less attractive for developing countries than for industrial countries.
34 However, there are other elements in the calculus that could go the other way, such as the likelihood of
35 higher relative future damage from global warming for the developing countries (see chapter 6).

36
37 Specific applications in the still new economic literature on global warming have adopted important
38 differences in estimation of the discount rate. In a benefit-cost analysis of greenhouse abatement, Cline
39 (1992) adopts a zero rate of pure time preference (ρ), and sets the SRTP at 1.5% per annum, the result of
40 an assumed consumption growth rate of 1% per capita multiplied by an elasticity of marginal utility of 1.5.
41 After taking account of the share of resources coming out of capital (20% economy-wide, versus 80% out of
42 consumption) and shadow-pricing capital effects (at a price of about 1.6 ***** JOE: This number seems to be**
43 **wrong. Alternative ... "The shadow price of capital with an SRTP of 1.5% and a capital return of 8 percent**
44 **would be 5.3."** This assumes geometric depreciation. If only 20 percent of the costs come from capital,
45 then a shadow price of 5.3 would lead to a weight on costs of 1.87. Moreover, if 10 % of net returns are
46 reinvested, then the shadow price of capital rises to 10.3, and the weight on costs rises to 2.86 --R. Lyon
47 ***** consumption for each unit of investment, based on 8 percent return on investment and 15-year life for**
48 **typical capital stock), Cline's effective discount rate is closer to 2 per cent. This is in keeping with recent**
49 **work by Pearce and Ulph (1994).**

50 51 3.4 Formulation of Descriptive Approach

52

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

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:

- Do nothing (year 0), do nothing (year 50)
- Do nothing (0), build sea wall if necessary (50) --
- Mitigation project (0), do nothing (50)
- Other investment (0), build sea wall if necessary (50)

The stream of benefits is as follows:

Option (year)	0	...	50	51	52	...
a.	0	...	0	0	0	...
b.	0	...	-10	1.0	1.0	...
c.	-1	...	1.0	1.0	1.0	...
d.	-1	...	1.1	1.1	1.1	...

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

An important difference between the two approaches is that the descriptive approach includes the opportunity cost of capital directly, while the prescriptive approach includes it indirectly, as the box

illustrates. Most global warming optimization models (e.g. Nordhaus, 1993a, b; Peck and Teisberg, 1992; Manne et al., 1993) rely on the descriptive approach. In practice, both approaches may lead to similar results, and similar policy recommendations.

3.4.1 Returns to Investment

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

Further, selecting a discount rate of 2% implies 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. But even if savings could be increased enough to drive the discount rate to one or two 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:

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

That opportunity costs (market rates of return) usually exceed the SRTP suggests the existence of better alternatives than those barely satisfying, say, a two percent rate of return criterion. At this point the question becomes: why has the SRTP not been brought into accord with observed market rates of return? It is sometimes argued that other alternatives are not feasible. If the long-term consumption rate of discount is 1% to 2%, say the prescriptionists, then a climate change investment returning 2% is better than no investment at all. To the argument that a discount rate of 2% is glaringly inconsistent with observed behavior (e.g., government spending on education or research, development assistance by donor countries), prescriptionists reply that just because the government fails to allocate resources properly in one area is no reason to insist that decisions in other areas be consistent with that initial decision.

3.5 Discounting for Risk

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

There would seem to be an argument for varying the growth-based component of the SRTP with respect to risk, however. If there is uncertainty about the rate of per capita income growth, g , then consider the effect on the component θg in the SRTP. Suppose there are two scenarios each with 50 percent probability: per capita income growth of 1 percent and per capita growth of 2 percent. There will be two resulting possible streams of marginal utility over time. The stream of expected value of marginal utility will be the average of these two streams. But because of diminishing marginal utility *** More than diminishing MU is being assumed here. With linear MU, for example, the simple average holds ***, 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 *** The last 2 sentences seem to contradict each other ***. 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.

3.6 Producer or Consumer Interest Rates?

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

But these assumptions are not generally satisfied, as evidenced by the marked discrepancy between the lower interest rates on savings typically facing consumers and the higher rates earned on investments by producers.

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

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

In special cases, however, one of the other three schools of thought may be correct. For instance, if the government were comparing two projects, both of which cost the same, and both of which yielded their output in the same year, then a comparison of the rates of return would provide an appropriate basis of choosing among projects. 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 ***** JOE: What is this last sentence saying? *****. There is a large literature emphasizing different aspects of the adjustment methodology. One body of literature emphasizes the effects on consumption versus investment, deriving a weighted average of the consumption and investment rates of return, with weights depending on the respective importance of the sources of finance (Sandmo and Dreze, 1971). Within the literature on optimal taxation and production (where the discrepancy between producer and consumer rates of interest arises from optimally determined tax rates), if the government is relatively unrestricted in the set of commodity taxes that it can impose, the producer rate of interest should be used to discount (Diamond and Mirrlees, 1971; Pestieau, 1974). However, in the more relevant regime in which government faces constraints on the sets of taxes that are imposed, there is no simple relationship between the appropriate public sector discount rate and the producer interest rate (Stiglitz and Dasgupta, 1971, Stiglitz, 1985, 1988).

3.7 Discounting Environmental Impacts

The essence of social discounting is to convert all effects into their consumption equivalents at the proper relative prices, and then to discount the resulting stream of consumption equivalents at the social rate of time preference. Incorporating environmental effects thus does not change the SRTTP 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 ***** Last sentence seems to contradict earlier part of para, which says that preferences for environmental goods can be taken into account by the benefits estimates. Now it is suggested that market interest rates are a bad way to discount the consumption bundle. Why do we advocate both lowering the discount rate for enviro goods and increasing their valuation? *****. The appropriate procedure entails converting the environmental change into contemporaneous consumption benefits, and discounting those.

***** JOE: Note change in this paragraph. It now says that net environmental degradation may occur, but some evidence points in the other direction. ***** Technical progress and structural change over the past several decades have resulted in improvements in most 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 some evidence that continued growth in per capital incomes will result in improved environmental quality. Some have supposed, however, that environmental degradation will occur as society grows (Weitzman 1993). If this occurs or, more likely, if the environment is an income elastic good on which people are willing to spend relatively more as their income rises, then the marginal rate of substitution between environmental quality and private goods will systematically change over time, toward a higher relative marginal value of the environment. This tendency will lead to a low (or even negative) effective discount rate for environmental amenities (see annex 3A). 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. ***** JOE: I find this explanation confusing. It seems to say that we need a lower discount rate for environmental amenities --Shouldn't this be captured in the benefits numbers rather than in the discount rate? -- but then says to use the SRTTP in evaluating the consumption stream.*****,

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 3.1, so long as consumption growth is positive there will be a nonzero SRTP. Similarly, some modern philosophers make the same mistake (e. g. Parfit, 1984; Cowen and Parfit, 1992).

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

3.8 Implications for Sustainable Development

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

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

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

Some have argued that the future damages from 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 non-linearities with major effects on the economy, particularly the economy of certain countries or regions.

Others have argued that if a longer time horizon is considered than that of the conventional benchmark of

1 2xCO₂, and if upper bound warming and damages are taken into account, and considering the range of
2 estimates for abatement costs, then even a standard economic analysis using the social discounting approach
3 outlined here can conclude that the benefits of aggressive action outweigh the costs on economic grounds
4 (Cline, 1992). This result obtains even though technical progress permits future per capita incomes
5 eventually to be much higher than present, because conventional estimates of the elasticity of marginal utility
6 the intergenerational bargain of exchanging modest costs today for large avoided damages in the future
7 remains an attractive one (Note that in Rawls' formulation, $\theta = \infty$). In this case, the two considerations just
8 noted simply reinforce this conclusion.

9
10 In many developing countries, Solow's definition would not be viewed as acceptable, since it seems to place
11 no weight on their aspirations for growth and development. Further, formal models analyzing optimal
12 development paths using a min-max (Rawlsian) criterion would, of course, focus exclusively on the welfare of
13 the less developed countries in the first place. But the prescription would be simple: massive redistribution
14 from the North to the South immediately, without introducing the complication of long-term environmental
15 problems. Even if there were limits on the transfers, it would suggest that all of the costs of mitigation--
16 including those occurring within the South-- be borne by the North.

17
18 Of course, even the utilitarian approach ($\theta < \infty$) would tend to lead to higher general income transfers to
19 poor countries than presently observed. Adherents of the descriptive approach would ask why the utilitarian
20 construct is appropriate when considering intergenerational equity (as in the identification of the SRTP
21 suggested in equation 3.1) if it is not applied in practice across (or, for that matter, within) countries at the
22 present. In one sense, this question is another application of the principle suggested above that in the
23 absence of optimal redistribution intervention by the government, observed market rates (in this case of
24 North-South transfers) will not necessarily or likely equal social rates. Alternatively, the equity norm
25 suggested here may not be widely shared by governments or voters.

26
27 Some might seek to explain the paucity of present-day North-South transfers on grounds of incentive effects.
28 Thus, the massive marginal tax rates on the North that would be required to equalize income levels with the
29 South could seriously reduce the amount of output available for redistribution. Perhaps more relevant (in
30 view of the modest but unfulfilled international targets for grant aid), the problems of still unaddressed
31 poverty within the North and sharp inequality within many developing countries complicate attempts to
32 improve overall welfare through North-South transfers. The fundamental explanation, however, is that each
33 country tends to consider primarily the welfare of its own citizens, and only secondarily that of others.

34
35 Despite the political constraints on present-day North-South transfers that would otherwise be recommended
36 by the utilitarian approach, the time-discounting concepts of that approach, and the SRTP in particular,
37 remain valid subject to these constraints. Thus, consider a matrix with two rows -- North and South -- and
38 two columns -- present and future. The SRTP can appropriately be applied between the two columns
39 along each row, even if there is a barrier to its application between the two rows. Leaders and publics in
40 developing countries have cause for concern about their descendants just as do their counterparts in
41 developed countries. As noted above, however, the value of the SRTP is likely to be higher for the South
42 row than for the North row.

43
44 At the same time, both the Rawlsian and utilitarian approaches imply that the South should actively engage
45 in mitigation financed by transfers from the North, so that efficient mitigation can be obtained. Any Pareto
46 efficient development path (including any reasonable definition of sustainable development) must have this
47 property of efficient mitigation. Thus, the level of mitigation should be set based on the eventual target of
48 greenhouse gas stabilization and implied levels of world emissions (without regard to where those emissions
49 originate). The magnitudes of actions required to attain those levels of world emissions will, of course,
50 depend on the rates of growth of the less developed countries as well as the increased energy efficiency
51 among both the developed and developing countries.

Annex 3A
Methodological Notes on Discounting

3A.1 Intertemporal Maximization of Well-Being

In an influential series of articles, Koopmans (1960, 1965, 1967, 1972a,b) conducted a series of thought-experiments on intertemporal choice so as to see the implications of alternative sets of ethical assumptions in plausible worlds. He suggested that we can have no direct intuition about the validity of discounting future well-beings, unless we know something concrete about feasible development paths. Applying this approach, Mirrlees (1967) and Chakravarty (1969) showed that in plausible economic models for developing countries, not to discount future well-being could imply that the present generation be asked to save and invest around 50 per cent of gross national product -- a stiff requirement when GNP is low. Nonetheless, these models tended to assume high rates of return on capital (a constant 33 percent rate in Chakravarty, 1969) and to consider time periods of decades rather than centuries. It is unclear that their findings hold for the centuries-scale problem

of global warming, in part because of the much lower likely average return to capital over this horizon.

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

$$3A.1) z = \int_{t=0}^{\infty} W(c_t) e^{-\rho t} dt$$

where $\rho > 0$.

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

$$3A.2) i_t = i(c_t) = \rho + \theta(c_t) [dc_t/dt]/c_t$$

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

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

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

As discussed in the text, the larger is the rate of pure time preference (ρ) the lower is the weight accorded to future generations' well-being relative to that of the present generation. Mirrlees's (1967) computations essentially introduced this sort of bias ($\rho > 0$) as a way of countering the advantages to be enjoyed by future generations, should the productivity of capital and technological progress prove to be powerful engines of growth.

As noted in the text, a higher value of θ means greater emphasis on intergenerational equity. As $\theta \rightarrow \infty$, the well-being functional in 3A.1) resembles more and more the Rawlsian max-min principle; in the limit, optimal growth is zero.

In 3A.3), $W(c)$ has no minimum value. If $\rho = 0$, this ensures that very low consumption rates are penalized by the optimality criterion reflected in (3A.1). On the other hand, if ρ were positive, low

consumption rates by generations sufficiently far in the future would not be penalized by (3A.1). This means that unless the economy is sufficiently productive, optimal consumption will tend to zero in the very long run. Dasgupta and Heal (1974) and Solow (1974a) showed in a model economy with exhaustible resources that optimal consumption declines to zero in the very long run if $\rho > 0$ ***** and in the absence of technical change? *****, but that it increases to infinity if $\rho = 0$.

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

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

Resource Sourcing and the Consumption versus Investment Discount Rate

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

They find that for a closed economy:

$$(3A.4) \quad 1+r < 1+i < 1 + r/(1-t)$$

where r is the consumer interest rate, t is the tax rate, and i is the public sector's discount rate. This rate should thus ***** JOE: is this obvious? ***** 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. 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. ***** What is the relevance of the Sandmo-Dreze discussion? Why do we need both a shadow price approach and a weighted average approach? *****

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

$$3A.5) U^t(c_t^t, c_{t+1}^t)$$

where the first argument refers to consumption the first period of the individual's life, the second to consumption the second period. Then observed market rates of interest refer to how individuals are willing to trade off consumption over their own life. These may or may not bear a close correspondence to how society is willing to trade off consumption across generations. The former corresponds to u_2^t/u_1^t , while the latter corresponds to u_1^{t+1}/u_1^t .

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 is a 100% pure profits tax *** What does this mean, and what is its relation to the zero-profit assumption? *** for there are no pure profits or rents), 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). *** JOE: Has this been published? Most readers will not know the assumptions underlying an unpublished paper ***

Effective Discount Rate for Environmental Impacts

As noted in the main text, the effective discount rate for environmental effects can be low or even negative. Assume there is a Cobb Douglas utility function between private goods, c , and the environment, e :

$$3A.6) u = a \ln c + b \ln e$$

Assume c increases at the rate g_c , and e decreases at the rate $-g_e$. Then the derivative of the marginal rate of substitution between the two goods is:

$$3A.7) d \ln MRS / dt = a g_c + b g_e$$

With no pure rate of time preference, consumption is discounted at the rate g_c , so environmental goods are discounted at the rate: $(a-1) g_c - b g_e$, which will be negative. *** JOE: Again, shouldn't we be adjusting either the valuation or the discount rate, but not both? ***

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6
7 **To be completed:**

8
9 Phelps, E. **Golden Rule article**

10
11 Meade, J. **Golden Rule article**

12
13 Robinson, J. **Golden Rule article**

14
15 Beltratti, Chichilnitsky, and Heal, ... **Green golden rule article**

1PCC

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FAX TO: JOE STIGLITZ

CEA

ADDRESSEE'S FAX NUMBER (202) 395-6958

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FAX FROM: RAY SQUITIERI

U.S. TREASURY

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COMMENTS/SPECIAL INSTRUCTIONS:

325 X 225
225
225

Fax Mr Squitieri

00-1-202-622-1294

To: Ray Squitieri
Treasury
Fax 00-1-202 622 1294

From: Ruby Saha
Fax (230) 212 42 40
(230) 212 93 69

Date: 20th December, 1994

Dear Ray,

It was good to see you and the other members in Washington last week. Sorry I missed you on the way out. I was with Sally Kane and Professor Goldemberg.

I received your summary last week, but was unable then to respond. Hereunder now, are my comments.

- (i) The summary is generally well organised. Congratulations on a fine piece of work.
- (ii) Para 4, in my opinion, mixes up the legal framework, which is a "chapeau" with devices and mechanisms, which eventually find their enforcement support within the legal framework. This mix up may be remedied by changing the second sentence of that paragraph to the following:

"Mechanisms for control of international public goods may include the definition of property rights, the definition of limits to emissions and a consensus for distributing the same in a fair and equitable manner."
- (iii) The following points should be made part of the summary, wherever they would be most apt.
 - The North has been a major contributor to the current levels of Green House Gases and contribute more than two thirds of total world GHG emissions today.

The cost of delay in emission reduction in terms of foregone opportunities of the countries of the South is substantial.

Ambiguities about the responsibilities of developing world to climate change will not persist for long. It will be necessary to promote policy measures to keep per capita energy consumption as low as possible.

I trust that you will take the above into consideration. You may wish to check the point raised at (ii) above with a legal specialist.

Please circulate to other Members of the Team.

Best Regards

Yours sincerely,

Ruby

Policy ... face two cars
of their action ... effect
of reducing greenhouse.

January 9, 1995

TO: Ruby Saha
Ministry of Housing, Lands, Town and Country Planning
Mauritius
fax: 230-212-9369 or -4240

FROM: Ray Squitieri
U.S. Treasury fax 1-202-622-1294

Dear Ruby,

Thank you for your suggestions on the Points for the Technical Summary. You will find your point (ii) has been inserted into the text (attached). The penultimate paragraph contains a modified form of your last bullet under (iii).

Your first bullet under (iii) would be appropriate if accompanied by a parallel statement that by the time significant warming effects occur, the North and South will have contributed roughly equal amounts to the stock then in the atmosphere. My concern is that including both points may raise the hackles of governments both North and South.

Your second bullet under (iii) can be included if a statement is also made to the effect that the South may also suffer if the North plunges ahead now with heavy spending on climate change mitigation. Why? First, the resulting loss of income in the North will cut into exports from the South (trade economists estimate that this effect might cut noticeably into growth rates in the South); second, because Northern spending on mitigation to help the South might well decrease other development aid from the North. To put this another way, suppose the North decides to spend a larger fraction of its output to increase life expectancy, improve education for women, raise living standards, etc. in the South. Then the South might be better off if the money were spent addressing these goals directly, rather than on climate change mitigation. I can't say for sure; it's an empirical question. Again, my concern is that raising this issue in the Summary may invite more political controversy than it's worth.

Joe will soon forward to you a copy of the Scope Chapter including the revisions discussed in Vienna.

I hope you are well, and that Mauritius is enjoying a tourist boom this winter with the recovery of the European economies. I look forward to seeing you again soon.

Ray

cc: J Stiglitz

IPCC SECOND ASSESSMENT REPORT WORKING GROUP III

Chapter 1: Scope of the Report -- Points for Technical Summary

Climate change presents the analyst with a set of formidable complications: large uncertainties, the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, an irreducibly global problem, wide regional variation, and multiple greenhouse gases of concern. The risks of climate change are highly asymmetrical, with a large probability of a small loss, and a small probability of a large loss. Even in the presence of significant uncertainty, this asymmetry, plus the principles of risk aversion and portfolio balancing provide the rationale for going beyond *no-regrets* policies to those that incur net costs.

The atmosphere is an international public good, in that all countries benefit from each country's reduction in greenhouse emissions; greenhouse gases are an international externality, in that emissions by one country affect all other countries to the same extent.

Both public goods and externalities require a legal framework within which the problems they pose can be addressed. Mechanisms for control of international public goods may include the definition of property rights, the definition of limits to emissions and a consensus for distributing the same in a fair and equitable manner. If, on the other hand, each agent acts in its individual interest, the result will be too little of the public good and too much of the externality.

Climate change demands a decision process that is sequential, can respond to new information with mid-course corrections, and can include insurance, hedging, and the option value of alternative courses of action. The challenge today is to identify short-term strategies in the face of long-term uncertainty. The question is not, what is the best course over the next 100 years, but rather, what is the best course for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.

Policy measures to reduce risks to future generations include 1) immediate reductions in emissions; 2) R&D on new supply and conservation technologies; 3) continued research on how much change is likely and what its effects will be; and 4) investments to assist in adaptation if significant global warming occurs. A well-chosen portfolio of policies will yield greater benefits for a given cost than any one option undertaken by itself. Striking the appropriate balance requires taking into account costs, benefits, and risks.

In an interrelated global economic system, an attempt to reduce greenhouse gas emissions in one region or one sector of the economy may be offset by increases in other regions or sectors. This may occur through a) the loss of comparative advantage in the carbon-intensive sectors of the regions that limit emissions; b) the relocation of industries; or c) changes in world energy prices and the resulting shift in consumption.

Any control strategy must account for these global effects.

Issues of efficiency and equity can largely be separated. The Framework Convention on Climate Change calls on all parties to implement cost-effective measures for abatement, enhancement of sinks, and adaptation. The Framework Convention also explicitly requires an equitable sharing of the burdens of response, recognizing the common but differentiated responsibilities of the parties. Different countries will be affected differently by climate change and by policy responses to it. The South is more likely to be adversely affected than the North; moreover, developing countries often lack the financial and technical resources to respond. The Framework Convention does not, however, include a formula for sharing the costs of addressing climate change.

Efficiency requires that emission reductions occur where their cost is lowest, irrespective of who bears the financial responsibility. Efficiency calls for removing energy subsidies, reforming and clarifying property rights that affect energy use and carbon storage, and reducing non-greenhouse externalities that have the side benefit of reducing greenhouse emissions. Efficiency may also be promoted, and greenhouse emissions reduced, by better information dissemination and by addressing capital market imperfections that inhibit the adoption of energy-efficient technology. Dynamic analysis indicates large potential gains from flexibility in timing of greenhouse reductions to allow for the economical turnover of capital stock, and to allow time for the development of low-cost substitutes. Policies that promote efficiency by requiring nations to face the full costs of their actions will also address equity concerns.

Efficiency also calls for international mechanisms such as joint implementation and coordinated economic instruments. Coordinated carbon taxes and tradable carbon emission permits can correct the market failure associated with greenhouse emissions.



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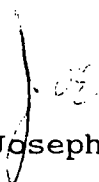
MEMBER

January 9, 1995

Dear Ram:

Thank you for your invitation to participate in the writing of the Synthesis Report, which I am pleased to accept. Given the importance of the Synthesis report, I did want to express one major concern: the creditability of the entire IPCC process and its usefulness for future Framework negotiations will depend critically on its reflecting accurately the general consensus of the economic science community. I was accordingly surprised to see that there was only one other "establishment" economist among the list of fifteen prospective members. I think it would be highly desirable to have one other economist, preferably with a strong empirical bent, such as Richard Richels, Jae Edmunds, or John Wyant.

Sincerely,


Joseph E. Stiglitz

Dr. Narasimhan Sundararaman
Secretary of the IPCC
IPCC Secretariat
World Meteorological Organization Building
41 Avenue Guisepe-Motta, C.P.N. 2300
1211 Geneva 2
SWITZERLAND



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



To: Prospective members (See attached list)

cc: Prof. B. Bolin
Chairman of the IPCC

From: N. Sundararaman
Secretary of the IPCC

Date: 20 December 1994

Subject: IPCC Drafting Team on the IPCC Study of Article 2
of the UN FCCC - nominations

Total: 5
Pages

Dear Colleague,

1. As you know, the IPCC will write a Synthesis Report (the IPCC Synthesis Report or ISR) based on a review of its Working Groups' Summaries (see IPCC Procedures for Preparation, Review, Acceptance, Approval and Publication of IPCC Reports). The IPCC has also been engaged in examining scientific-technical issues related to achieving the objective (Article 2) of the Climate Change Convention. A workshop on the subject has been held in Fortaleza (17-21 October 1994). The Synthesis Report will include the results of the IPCC examination of Article 2. An underlying report may also be prepared by the IPCC.

2. The ISR has to be drafted, reviewed, revised and approved line by line by the IPCC. It will undergo review sequentially by selected experts and by governments before submission to IPCC for approval. The approval will take place at the eleventh session scheduled for Italy (exact venue to be specified) on 11-15 December 1995. A Drafting Team will be formed under the chairmanship of Prof. Bolin to draft the ISR and to prepare any underlying report. The underlying report will not undergo approval.

3. The IPCC Chairman, the Co-Chairs of the Working Groups viz., Sir John Houghton, Drs. Meira Filho, Watson, Zinyowera, Bruce and Hoesung Lee, the Leaders of the 3 Technical Support Units viz., Drs. Callander, Moss and Haites and the IPCC Secretary will form the core of the Drafting Team. The core team is responsible for the completion and the approval of the ISR.

4. The philosophy of selecting the other members of the Drafting Team has been to achieve, as far as practicable, a balance both geographically and in points of view and to invite persons of international eminence who are very active in relevant subject areas including policymaking.

5. The core team invites you to be a member of the Drafting Team. If you agree, you will have to attend a meeting in Athens from 1 to 4 May 1995 (the IPCC Trust Fund will support the travel of the members from the developing and transitional economy countries). The schedule is tentative with regard to 4 May. A proposed schedule for the completion of the Synthesis Report is attached.

6. Can I have your response as to your willingness to serve on the Drafting Team as soon as possible but no later than 9 January 1995?

Many thanks and regards. Happy Holidays.

Yours sincerely,



N. Sundararaman

Proposed Time Table for the completion of the
IPCC synthesis report

All dates are in 1995

Activity	Deadline
First draft to be ready	April 10
First Meeting of the Drafting Team, Athens	May 1-3 (possible stay over for some on May 4)
Result: Second draft for review by selected experts	
Selection of experts for this review	
Second draft mailed for review by selected experts	May 8
Time for return of reviews: 4 weeks	
Experts' Reviews due	June 6
Reviews collated and sent to Drafting Team	June 26
Second Meeting of the Drafting Team, London	July 3-5
Result: Third draft for governments' review	
Dispatch of third draft for government review	July 10
Time for return of reviews: 8 weeks (required: 6 weeks)	
Reviews received from governments	September 4
Reviews collated and sent to Drafting Team	September 20
Third Meeting of the Drafting Team, Washington D.C.	September 27-29
Result: Final draft for approval at IPCC-XI	
Dispatch of the final draft to governments: 6 weeks (required: a month)	October 30
Approval of final draft, IPCC-XI, Italy	December 11-15

Prospective members:

J. Stiglitz	USA	Lead Author, Chapter I, WG III
M. Parry	UK	Convening Lead Author, IPCC Guidelines for Assessing Climate Change Impacts and Adaptations
J. Melillo	USA	Lead Author, WG I/WG II
J. Goldemberg	Brazil	Convening Lead Author, Chapter I, WG III
Martha Perdomo	Venezuela	Co-Chair, Subgroup D/WG II
Tariq Banuri	Pakistan	Lead Author, WG III on equity & social considerations
Zhou Dadi	China	Lead Author, Chapter on emission scenarios, WG III
R. Odingo	Kenya	Co-Vice-Chair, WG III
Roberto Acosta Moreno	Cuba	Lead Author, Energy Supply Mitigation Options, WG II
Penny Wensley	Australia	Ambassador for environment and to UN in Geneva, Vice-Chairman of INC/FCCC
I. Mintzer	USA	Lead Author, WG III
M. Jefferson	UK	Lead Author on energy supply mitigation options (WG II), World Energy Council
B. Gardner	USA	Represents US industry, such groups as Climate Council

J.-C. Hourcade	France	Economist, lead author on the costs of mitigation (WG III)
TBD	TBD	Impacts expertise preferably water, nomination awaited from Bob Watson

Please note that the WMO, and hence the IPCC Secretariat,
will remain closed from 24 December 1994 to 2 January 1995,
reopening on 3 January 1995.



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



To: Prospective members (See attached list)
 CC: Prof. B. Bolin
 Chairman of the IPCC
 From: N. Sundararaman
 Secretary of the IPCC
 Date: 20 December 1994
 Subject: IPCC Drafting Team on the IPCC Study of Article 2
 of the UN FCCC - nominations
 Total: 5
 Pages

Dear Colleague,

1. As you know, the IPCC will write a Synthesis Report (the IPCC Synthesis Report or ISR) based on a review of its Working Groups' Summaries (see IPCC Procedures for Preparation, Review, Acceptance, Approval and Publication of IPCC Reports). The IPCC has also been engaged in examining scientific-technical issues related to achieving the objective (Article 2) of the Climate Change Convention. A workshop on the subject has been held in Fortaleza (17-21 October 1994). The Synthesis Report will include the results of the IPCC examination of Article 2. An underlying report may also be prepared by the IPCC.

2. The ISR has to be drafted, reviewed, revised and approved line by line by the IPCC. It will undergo review sequentially by selected experts and by governments before submission to IPCC for approval. The approval will take place at the eleventh session scheduled for Italy (exact venue to be specified) on 11-15 December 1995. A Drafting Team will be formed under the chairmanship of Prof. Bolin to draft the ISR and to prepare any underlying report. The underlying report will not undergo approval.

3. The IPCC Chairman, the Co-Chairs of the Working Groups viz., Sir John Houghton, Drs. Meira Filho, Watson, Zinyowera, Bruce and Hoesung Lee, the Leaders of the 3 Technical Support Units viz., Drs. Callander, Moss and Haites and the IPCC Secretary will form the core of the Drafting Team. The core team is responsible for the completion and the approval of the ISR.

Post-It™ brand fax transmittal memo 7671		# of pages > 5
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199 OMM CH

4. The philosophy of selecting the other members of the Drafting Team has been to achieve, as far as practicable, a balance both geographically and in points of view and to invite persons of international eminence who are very active in relevant subject areas including policymaking.

5. The core team invites you to be a member of the Drafting Team. If you agree, you will have to attend a meeting in Athens from 1 to 4 May 1995 (the IPCC Trust Fund will support the travel of the members from the developing and transitional economy countries). The schedule is tentative with regard to 4 May. A proposed schedule for the completion of the Synthesis Report is attached.

6. Can I have your response as to your willingness to serve on the Drafting Team as soon as possible but no later than 9 January 1995?

Many thanks and regards. Happy Holidays.

Yours sincerely,

Hundarlamay

N. Sundararaman

Proposed Time Table for the completion of the
IPCC synthesis report

All dates are in 1995

Activity	Deadline
First draft to be ready	April 10
First Meeting of the Drafting Team, Athens	May 1-3 (possible stay over for some on May 4)
Result: Second draft for review by selected experts	
Selection of experts for this review	
Second draft mailed for review by selected experts	May 8
Time for return of reviews: 4 weeks	
Experts' Reviews due	June 6
Reviews collated and sent to Drafting Team	June 26
Second Meeting of the Drafting Team, London	July 3-5
Result: Third draft for governments' review	
Dispatch of third draft for government review	July 10
Time for return of reviews: 8 weeks (required: 5 weeks)	
Reviews received from governments	September 4
Reviews collated and sent to Drafting Team	September 20
Third Meeting of the Drafting Team, Washington D.C.	September 27-29
Result: Final draft for approval at IPCC-XI	
Dispatch of the final draft to governments: 6 weeks (required: a month)	October 30
Approval of final draft, IPCC-XI, Italy	December 11-15

Prospective members:

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TBD

TBD

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preferably water,
nomination awaited from
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Discounting

Delete first par. and add

The approach upon which ~~this chapter~~ ^{described in the next section} focuses is sometimes called the prescriptive approach. It simply asks, given a plausible social welfare function, whether a particular program would make society better off. The discounting rules specify how consumption at different dates should be valued to provide the "correct" answer to that question.

There ~~is~~ ^{the} an alternative view, ~~which~~ ^{described later in the next section} focuses on intertemporal efficiency and opportunity costs, ~~and to distinguish itself from~~ the prescriptive approach is sometimes referred to as the descriptive approach. It asks, is the proposed program consistent with intertemporal efficiency, i.e. could we increase consumption at one date without decreasing it at any other? If a policy is not intertemporally efficient, it should not be adopted. The fact that opportunity costs (market rates of return) typically exceed S RTP suggests that there frequently exists alternatives which dominate a program which just barely satisfies, say, a 2% rate of return criteria. The central problem in evaluating these alternatives, however, is ascertaining the relevant constraints: why is that the S RTP has not been brought into accord with observed market rates of return? Thus, there may be some reason that the proposed dominating alternative may not really be a feasible alternative.

*****To be added somewhere

Thus, the central difference between the two approaches is that one asks, is the proposed program an improvement? while the other asks, is this the best of all possible actions?

*****To be added somewhere

It is important to emphasize that in using the S RTP approach, we value the total change in consumption at each date, not just the direct outputs of the project. If the project displaces private investment, which has a high marginal productivity, then there will be a large loss in output and consumption resulting from the displacement. The prescriptive view takes into account opportunity costs in calculating changes in consumption, but in valuing the changes in consumption, uses the S RTP.

Refer (LMD) to
 $r_b = S RTP = \rho + \Delta g$
 in equation

(A)

1.1 INTRODUCTION

In recent years, atmospheric emissions of greenhouse gases have risen significantly. Concentrations are currently about 25 percent greater than at the beginning of the Industrial Revolution. If current trends continue, concentrations will double from pre-industrial levels by the end of the next century and, if unchecked, continue to rise thereafter (IPCC 1990).

The scientific community has noted the potentially serious effects of increased concentrations. These climatic effects could, in turn, have further effects on the biosphere, including an increase in mean global temperature, an increase in sea level, changes in agricultural yields, forest cover and water resources, and a possible increase in storm damage.

Increased concentrations of greenhouse gases are the result of fossil fuel burning, livestock raising, and other human activities. Concerted action on the part of individuals and governments will be required to slow the increase in concentrations. Changes in greenhouse gases concentrations and the analysis of the climatic and other physical consequences of those changes lie within the purview of the physical sciences. The consequences of those changes for humans, as well as possible responses, lie within the purview of the social sciences.

Climate change impacts are likely to vary dramatically from country to country. A warmer climate will benefit some mid- and high-latitude countries. At the same time, a rising sea level and the possibility of increased storm surges could threaten the survival of some small island states and coastal areas, and could increase the risk of drought and desertification for inland areas on the periphery of deserts.

Within the past decade, a consensus has emerged on some key issues in the economics of climate change. This report describes areas of consensus, as well as areas of disagreement, the sources of disagreement, and further research that could narrow the range of disagreement. This chapter frames the issue of climate change largely from the point of view of economics but also from that of other social sciences, introducing the more detailed discussions in the chapters to follow.

The commitment of resources to mitigate climate change may rest on one of two arguments. The first arises from fundamental values, the second from decision analysis:

1. We have only one planet. Some changes are largely irreversible, and may occur rapidly. Prudence calls for avoiding a large-scale experiment with the planet. Thus, avoiding climate change lies beyond normal economic calculus.

2. The potential exists for large, sudden, irreversible non-linearities with major effects on the economy, particularly the economy of certain countries or regions.

Even if the first view is adopted, economics has much to contribute to the discussion, for the question of cost-effective emissions reductions must still be addressed. If the second view is adopted, economics will clearly be relevant.

This chapter, and others in this Assessment Report, draw on the findings of Working Groups I and II, and follow the guidelines provided by the Framework Convention. That Convention makes clear that important questions remain to be addressed by subsequent negotiations, including the adequacy of national commitments. This chapter takes the Framework convention as a political document, recognizing that particular terms of the agreements reached by international negotiation may or may not accord with accepted scientific research; that for instance, the agreements may or may not have provided the basis of a cost-effective approach to mitigating climate change. It is hoped that the findings of this chapter and the assessment report more broadly will enhance an understanding of the costs and consequences of alternative

role of
human
activity
is general
greenhouse
processes

both in ascertaining the extent of mitigation strategies as well
as the
determining
them
design.

greenhouse gases is not defined

1 actions, and will provide the scientific basis for ongoing negotiations.

1.2 FEATURES OF CLIMATE CHANGE

Climate change could impose a variety of impacts on society. IPCC Working Group II analyses these impacts in detail. They include effects on agriculture¹, forests², water resources³, the costs of heating and cooling⁴, the impact of a rising sea level rise on small island states and low-lying coastal areas⁵, and a possible increase in storm damage. Although most attention to date has focused on negative impacts, some impacts will be positive. Beyond these tangible impacts are a variety of intangible impacts⁶, including damages to existing ecosystems and the threat of species losses⁷.

Climate change presents the analyst with a set of formidable complications: large uncertainties, the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, an irreducibly global problem, wide regional variations, and multiple greenhouse gases of concern.

Large uncertainties. While scientists agree that "greenhouse gas emissions are rising, they do not agree" about the mechanism linking concentrations, temperature, and well-being. Further, although scientists agree that some warming will occur, they do not agree on the speed of change, or the ultimate amount of change (IPCC 1992, 1994). In addition to these uncertainties, social scientists do not agree on the size of behavioral responses to climate change policies. *economic effort*

Nonlinearities and irreversibilities. Nonlinearities occur when changes in one variable cause a more than proportionate impact on another variable. For example, some have suggested that even a modest increase in atmospheric greenhouse gas concentrations could, beyond a certain point, trigger a substantial increase in temperature. Alternatively, even a modest increase in average temperature might significantly increase weather-related agricultural losses because, for many crops, extra days of extreme heat severely limit yields. In Figure 1, if the threshold temperature for crop damage is T_0 , then even a small increase in the mean temperature, from m_1 to m_2 , may greatly increase the number of days above the threshold, represented by the area under the curves to the right of T_0 ⁸. Irreversibilities are changes that once set in motion cannot be reversed, at least on human time scales. "Runaway warming" that some have hypothesized is an example. Some oceanographers have expressed concern that warming might disrupt the deep cold-water current of the North Atlantic Conveyor, responsible for much of the oceans' carbon uptake. Once disrupted, this current might not revert to its original position for centuries⁹.

Long planning horizon. Greenhouse gas concentration changes occur over a long period of time, with the full consequences of actions taken over the coming decades being felt in future centuries. The truly long term nature of the problem is one of the distinctive aspects of greenhouse gas warming. Seldom has the world consciously faced a set of decisions likely to affect our descendants one, two, or three centuries from now. Because the costs of taking action today are born by the current generation, while the benefits accrue possibly hundreds of years in the future, the world community is now faced with issues of intergenerational equity on an unprecedented scale. While society has addressed similar problems concerning trade-offs over periods of fifty or even a hundred years, the long planning horizon for climate change puts the analytic questions at issue in a new light. The length of time involved has one further implication: changes in technology, as well as population and consumption patterns, become of paramount importance.

Slow pace of change. Every country has made large capital investments in its cities, farms, ports, etc. Some of this investment cannot be changed without large costs: low-lying port cities, for example, cannot easily be rebuilt. For other investments, the cost of change will be small; for diversified agricultural economies, the cost of switching from one annual crop to another will be small if the temperature increase is on the order of 0.2°C. to 0.3°C. per decade, as climate scientists now expect (IPCC 1994)¹⁰.

Time lags. Atmospheric concentrations, rather than emissions, determine the amount of warming that

*process for countries for internally set choices, in clearly your
population policies and emission reduction of environmental assets
(like the land change). This is*

besides species loss at other ecosystem damage,

1980; Hoffman *et al.*, 1983; Hoffman *et al.*, 1986). The current "best estimate" for mean global sea level rise by 2030 under "business as usual" is 18 cm (Warrick, Oerlmans *et al.* 1990; Raper *et al.*, 1990).

A rising sea level could inundate some small island nations, flood some low-lying coastal cities (e.g. in Bangladesh), damage coastal farmland, and contaminate water supplies (IPCC, 1990a). More severe storms would accelerate coastal erosion and affect aquifers, intensifying problems existing today. Warmer oceans might damage coral reefs, a natural defence for some coastal areas. To account for the costs of protective measures, the costs of defending the world's developed coastlines against a 1 m rise over the next 100 years have been estimated to range from 0.01% for the former USSR to 0.74% for Indian Ocean small islands, with a world average of 0.028% of GNP per annum (IPCC, 1992).

6. Some analysts ~~have found tangible costs to be small~~, and believe that the justification for costly and more restrictive actions rests on intangible costs (Nordhaus, 1993), ~~which remain poorly quantified~~. Intangible costs include migration, comfort, health, leisure activities, urban infrastructure, and air pollution (Fankhauser ****date****, Cline (1992)). A warmer climate would improve human comfort in cold areas, and in the winter generally, while decreasing comfort in warm areas. Mearns *et al.* (1984) calculate a threefold increase in heat waves for a 1.7 degree C. rise in U.S. mean temperature. It is not yet clear whether net comfort will rise or fall for a given rise in temperature.

7. Both the natural rate and human contribution to the process of species loss are difficult to estimate (EPA, 1989). It is even more difficult to predict the effects of climate change on species distribution. Uncertainty about the timing of changes in climate, the duration and type of environmental changes that would be caused by climate changes, and the combination of human and environmental driving forces would influence species diversity make the long-term projection of species change highly complex. Moreover, while some species may have difficulty adapting to climatic changes, opportunities for other species may open up. Population pressures have added to pressure on ecosystems, particularly in the third world. Climate change may exacerbate these damages, particularly in Africa, where environmental degradation has been particularly pronounced during the last 15 years (UN, 1989).

8. A warmer climate might also increase climate variability, though climatologists cannot say with assurance whether climate will become more or less variable daily and seasonally. The normal variability of existing climate also makes it difficult to detect any warming that might be occurring. The "signal to noise" problem makes it possible for observers to mistakenly consider a normal extreme event as evidence of a trend, or to fail to see a trend in a noisy data series. Because of the signal-to-noise problem, the scientific community is unable to indicate confidently whether extremely warm years of the 1980's are evidence of climate change or not (A. Solow 1992 - check date-).

9. Recent ice core data from Greenland points to earlier temperature rises of several degrees occurring within a few decades (IPCC 1994); reasons for these sudden changes are still not understood, but might have come from changes in deep ocean currents. The other side of this debate holds that on the whole the biosphere is homeostatic or self-correcting; this "Gaia hypothesis" compares the biosphere to a living being: once moved away from equilibrium, self-correcting forces naturally move it back to equilibrium (Lovelock, **date *****).

10. Nations with less diversified agricultural sectors, including small island states, would incur higher costs from such a transition.

11. Scientists do not agree on how to measure the warming potential of different greenhouse gases (IPCC, 1992). Although global warming potential (GWP), endorsed by the IPCC, is a useful concept in formulating comprehensive approaches to greenhouse mitigation policies (Stewart and Wiener, 1990), some analysts have recently criticized the concept on the grounds that GWP implicitly sets the opportunity costs of an increment

hypothesis are not necessarily inconsistent. Within a range of varying host, homeostatic properties could dominate, ... it would free nature to rise.

1
2 **1.8 ENDNOTES**
3

4 1.A warmer climate would directly affect the temperature-sensitive sectors of the economy: agriculture,
5 forests, and fisheries; and construction. Because of the risk of drought, arid and semi-arid regions are likely
6 to be most vulnerable to warming. A warmer climate may also encourage insect populations; this, in turn, is
7 likely to decrease agricultural yields in some regions. On the other hand, increased CO₂ concentrations
8 increase photosynthesis and the effect of water consumption in controlled settings, and may also do so in
9 farmers' fields, increasing crop yields.
10

11
12 A warmer climate would hurt agriculture in some regions and help in others. Recent global studies find that
13 Northern temperate regions could benefit, particularly for small increases in temperature, but low latitude
14 areas could lose. The global studies show significant losses from climate change alone that are significantly
15 offset by the direct beneficial effects of higher ambient levels of carbon dioxide on plant growth. Reilly, et
16 al. (1994?) calculate that global agricultural production will increase for global mean warming of up to 2°C.
17 Most analysts expect that agriculture can adapt without significant added costs for the world as a whole
18 (although some regions will suffer greater-than-average losses), in part because of crop shifting and other
19 adaptation by farmers, and because of the moderating influence of trade in international commodity markets
20 (Ausubel, 1990; Rosenzweig and Parry, 1994; Reilly, Hohmann, and Kane, forthcoming; Kane, Reilly, and
21 Tobey, 1992). Some have concluded that world agriculture would, on balance, benefit from warming of up to
22 2°C (Reilly 1993).]

23 2.A warmer climate implies both a poleward movement of forests and changes in forest composition. The
24 result would be to increase boreal forests and, by a smaller percentage, to decrease tropical forests. On
25 balance, doubling CO₂ concentrations would modestly reduce both standing biomass and forest area (Sedjo
26 and Solomon, 1989). Some analysts also calculate an additional temporary decline in forest cover during the
27 transition to a warmer climate (EPA, 1989); this decline could last for several hundred years, as more forest
28 death occurs on southern edges than additional growth occurs on northern edges. Higher CO₂
29 concentrations might also increase tree growth, partially offsetting direct losses from warming.

30 3. Some analysts conclude that a warmer climate would significantly reduce water supply (Gleick, 1987). Most
31 climate models now predict hotter and drier weather for the mid continents (IPCC, 1990a). If this occurs,
32 the downward pressures on water supply will be intensified by upward pressures on water demand.
33

34 Because of the key role of local conditions, further generalizations are difficult. River basin runoff is the
35 difference between precipitation and evaporation plus absorption (IPCC, 1990a). Hence small variations in
36 these three terms--each of which depends on the accuracy of regional climate forecasts--can make a large
37 difference in the runoff.

38
39 4. A warmer climate implies reduced heating costs and greater cooling costs. At least for countries in
40 temperate and cool climates, this would move the population-weighted average temperature closer to the
41 ideal indoor temperature. Nordhaus (1991) finds that warming of approximately 3.0°C in a 1981-sized U.S.
42 economy will increase electricity costs by \$1.65 billion and decrease heating costs by \$1.16 billion (1981
43 dollars), resulting in net costs of \$0.49 billion. Rosenthal, Gruenspecht, and Moran (1994) find that global
44 warming results in a net benefit to the U.S. economy. Cline (1992) finds net costs of \$9.9 billion.
45

46 5. Global mean sea level appears to have risen 10-20 cm over the past century (Warrick, Oerlemans et al.,
47 1990). The IPCC has projected a warming-induced rise in mean sea level of 21 to 71 cm by 2070 (IPCC,
48 1990a), sharply reduced from estimates of 3 to 8 m. made in the early to mid-1980s (Schneider and Chen,

occurs. Concentrations change much more slowly than emissions, meaning that affected nations might not have enough time to prevent warming damage or to mitigate economic impacts after the effects of climate change become evident. The combination of time lags in the climate system and uncertainty about effects requires taking action before unambiguous information emerges about timing and magnitude of climate effects.

Global scope. Climate change is a global challenge, which cannot be answered by a single country acting by itself. Mitigation must be coordinated globally. In an interlinked world economy, not only are the actions of a single country, or group of countries, not likely to be sufficient to address the problem, they are likely to be largely offset by actions of other countries. If, for instance, one group of countries reduces timber cutting to increase carbon absorption, then the price of lumber will rise, which may induce other countries to increase cutting in their forests. The net impact on world forests may be negligible, or even negative.

Regional variation. Impacts are likely to vary greatly both within and among countries. Some countries and regions will suffer from warming; others will benefit. Some cold countries will benefit from a reduction in heating costs and an increase in the length of growing seasons; some warm countries will see a drop in yields from agriculture and forestry; low-lying states are likely to suffer from increased storm surges and flooding. For the world as a whole, the net effect at any time will be the sum of local effects at many points on the globe, some positive and some negative; analysts have no simple way to estimate this sum.

Aggregation. On a priori grounds, there is no reason to believe that greenhouse warming should have in the aggregate, either positive or negative long-run effects (although adjustment implies costs in the short run). Indeed, studies twenty years ago focused on the dire consequences of global cooling. It seems unlikely that the earth is somehow endowed at this moment with the optimal temperature, *what is more likely is that it has adjusted to its current climate, and no adjustment is needed with climate, may be earth.*

Multiple gases of interest. Increases in radiative forcing (heat trapping ability) depend on the concentration of all greenhouse gases, not just CO₂, even though most economic modeling to date has limited itself to CO₂. Because different greenhouse gases have different atmospheric lifetimes, analysts have devised weighting schemes to make different gases commensurate¹¹.

Importance of net emissions. Because greenhouse gas concentrations depend on net rather than gross emissions, changes in forests and other carbon sinks must be taken into account¹².

Efficiency vs. Equity. How much to reduce emissions is a matter of efficiency. Who pays is a matter of equity. Economics has much to say about the former, but much less about the latter. Nonetheless, equity considerations will drive many of the policy decisions to be made under the Framework Convention on Climate Change.

0 The problem is worse than the drought drought because of impact interdependence between past and new investment. Even if it became apparent that a new project would be needed in 50 years, investment in the current project would continue for an extended period.