Environment and Development Economics 3 (1998): 347–409

Policy Forum

Introduction: Global climate change and the economics of development

Climate change is one of a small number of environmental problems that involve a global public good and a set of dynamics that is sufficiently ill-understood to make estimation of the long-run costs and benefits of current action highly uncertain. As with the spread of global infectious diseases it involves complex interactive feedback effects, wide geographical dispersion, and a link with the most pervasive of behavioural patterns. But the long-term dynamics of climate change are such that involves a different order of uncertainty. As with biodiversity loss, the costs and benefits of preventive or mitigating behaviour fall with unequal effect on rich and poor countries, and on current and future generations. Issues of equity and efficiency collide with more than usual force. But the incidence of costs raises a much more powerful set of national interests against mitigation.

This forum, prepared in the aftermath of Kyoto, reconsiders the economics of climate change in the light of an assessment on the state of the art offered by Bert Bolin to the eighth annual conference of the European Association of Environmental and Resource Economists. The statement, made as Chairman of the Intergovernmental Panel on Climate Change (IPCC), challenges economists in four areas.

- Anthropogenic climate change is a consequence of the interactions of socio-economic and biogeophysical processes. How may these interactions best be modelled in an integrated way?
- The long-term trends involved in climate change are related, in an ill-defined way, to short-term fluctuations and crises in the socio-economic system. How should the relationship between short-term fluctuations and long-term trends be understood and analysed?
- The IPCC doubts the benefits of conventional benefit–cost analysis as a tool for evaluating mitigation options, particularly those with very long-term effects. What alternatives are there?
- Neither climate change nor the mitigation of climate change is neutral in the effects it has on the well being of people living now and in the future. How should we address issues of intra- and inter-generational equity?

The Kyoto agreement may be argued to provide indirect evidence that we lack consensus as to the appropriate response to any of these challenges. This forum consists of invited comments on the statement by leading figures in the field in both North and South. It provides rather more direct evidence of the same thing. We might expect disagreement on issues of equity. But take the what seems to be the least contentious challenge: should we be attempting to analyse mitigation options using environmentally adjusted benefit–cost analysis? The forum includes diametrically opposed opinions from David Pearce and Tom Tietenberg.

There may be agreement at the level of principle, but because of the nature of the climate change problem, it is not always obvious how principles should be applied in particular cases. The forum does illustrate important areas of consensus. But it also shows that economics does not yet have agreed methods for addressing change in complex dynamical systems.

Charles Perrings
Editor

Key features of the global climate system to be considered in analysis of the climate change issue

Presentation to the eighth annual conference of the European Association of Environmental and Resource Economists Tilburg, 26–28 June 1997

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The global climate change issue

The threat of a human-induced change of climate and how to respond are issues of global political dimensions and part of the even broader political issue of sustainable development. Basic knowledge about the behaviour of the natural system, when subject to human-induced disturbances, as well as the global socio-economic system that we all are part of and that bring about these disturbances, is fundamental in order to address such issues in a rational way. Some researchers are attracted by the challenge to the sciences that is involved and wish to engage themselves, others are more hesitant about the possibilities to really analyse such a complex issue in a meaningful way. They therefore rather tend to become critical about the attempts that are being made. The systems with which we are concerned are indeed complex. A first question therefore naturally becomes: how

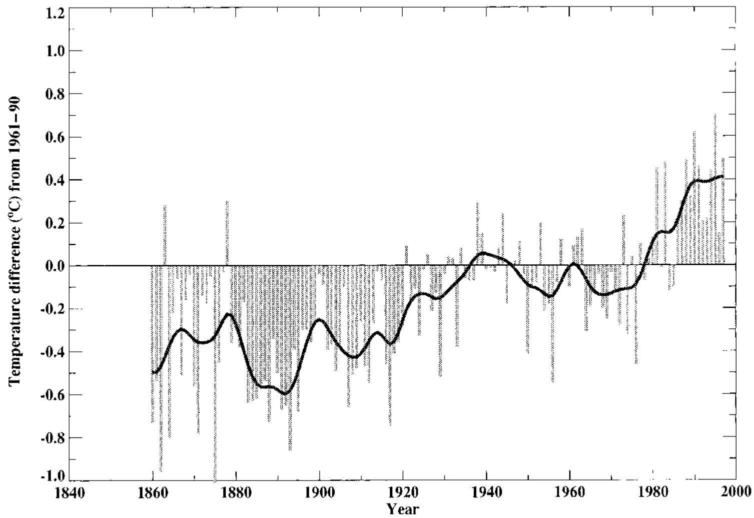

Figure 1 *Observed changes of the global mean surface temperature 1860–1994.*

shall we interpret the scientific findings that are presently available about this issue and is our knowledge adequate in order to understand what is happening and to initiate actions?[1]

Key features of the global climate system

Let us first recall some key features about the climate system. Present knowledge and recent scientific findings of relevance can be summarized as follows:

> *The global mean surface temperature has increased by about 0.5 degrees C during the twentieth century (cf. Figure 1).* In reaching this conclusion the possibly distorting effects of local heat sources ('urban heat islands') have been carefully considered. About half of this observed change has occurred during the last 50–60 years. Before that time human disturbances can hardly have been of a magnitude that could significantly have changed the climate globally and they therefore certainly are due to the natural variability of the climate system. This early record is, however, too short and probably not adequately rep-

[1] The present paper is largely based on the IPCC Second Assessment Report, 1995
(a) *Climate Change 1995* – 'The science of climate change', Report of the IPCC Working Group I. Cambridge University Press.
b) *Climate Change 1995* – 'Scientific-technical analyses of impacts, adaptation and mitigation of climate change', Report of IPCC Working Group II, Cambridge University Press.
(c) *Climate Change 1995* – 'The economic and social dimensions of climate change', Report of IPCC working Group III, Cambridge University Press.
(d) 'The IPCC second assessment synthesis of scientific-technical information relevant to interpreting Article 2 of the UN Framework Convention on Climate Change', IPCC Secretariat, World Meteorological Organisation, Geneva.

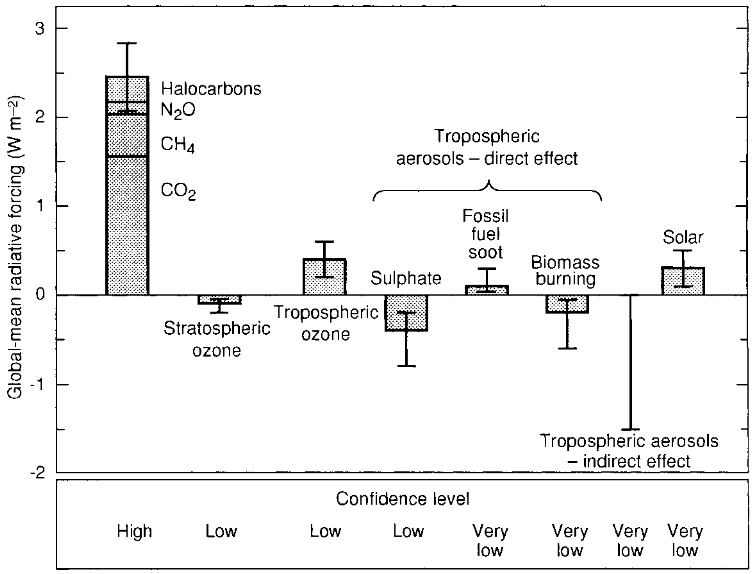

Figure 2 *Changes of radiative forcing (W/m2) in 1990 due to (1) enhanced concentrations of greenhouse gases, (2) decrease of ozone in the stratosphere because of increased halocarbon concentrations, (3) changes of the aerosol concentrations, and (4) changes of solar radiation during the twentieth century.*

resentative for the globe as a whole to reveal much about the magnitude of natural variability, particularly on time scales of half a century or more. If judging from this time series alone, the observed recent changes could therefore be the result of natural variations.

Atmospheric greenhouse gas concentrations (carbon dioxide, methane, nitrous oxide, halo-carbons, tropospheric ozone) *continue to increase and tend to warm the atmosphere.* Their combined effects are today equivalent to an increase of carbon dioxide by about 50 per cent, 30 per cent being due to enhanced concentrations of carbon dioxide itself. Most of these gases have mean life times in the atmosphere between ten and about 150 years and they therefore accumulate. Their long life times imply that they become quite well mixed and the increase of their concentrations is about the same all around the world. We can compute with reasonable accuracy the change in the radiative forcing of the global climate system that this change of greenhouse gas concentrations has brought about so far (about 2.4 W/m2). Thus the human-induced forcing due to increased greenhouse gas concentrations is about 1 per cent of the natural forcing caused by solar radiation (figure 2). It should be noted that the forcing shown in this figure includes the indirect positive feedback that is due to the increase in concentrations of water vapour, that is likely to have occurred due to the warming caused by the emissions of the greenhouse gases that influence the radiative forcing directly.

Enhanced concentrations of sulphate aerosols, resulting from combustion of *fossil fuels, and smoke from biomass burning, tend to cool the atmosphere globally*. These aerosols are, however, unevenly distributed over the globe, because of spatially varying emissions and short atmospheric life times (about a few weeks). This cooling effect is therefore patchy and declines quickly when emissions of the gases, that form aerosols, are decreased. About 90 per cent of the sulphur emissions come from burning sulphur rich fossil fuels. These emissions also contribute to acidification of precipitation, fresh waters, and soils and are therefore being reduced in industrial countries. Reduced use of fossil fuels with the aim to stabilize carbon dioxide concentrations in the atmosphere (see below) would lead to major reductions of sulphur aerosol pollution.

The inertia of the climate system and the cooling caused by aerosols means that the potential change in global climate due to emissions of greenhouse gases is partly hidden, and the increase in the global mean temperature, due to emissions so far, has probably been delayed (by 40–70%). This obviously makes the detection of an ongoing human-induced change in climate more difficult. The patterns of change that are brought about by the emissions of aerosols are, on the other hand, useful when analysing the observed changes in climate and when trying to determine their possible contribution to specific external factors.

Our ability to determine a possible human influence on the global climate is still limited because the expected signals, i.e., the patterns of change, are only just discernable from those of natural variability. In spite of these uncertainties, the IPCC has concluded that *'the balance of evidence suggests that there is now a discernible human influence on the global climate'.*

The sensitivity of the climate system to greenhouse gas forcing is, however, not yet well known. *The assessment of the equilibrium warming due a doubling of carbon dioxide concentrations in the atmosphere (or an equivalent change of other greenhouse gases) still has a wide range of uncertainty, 1.5–4.5 degrees C.*

The expected change of climate will most likely be unevenly distributed over the globe. We cannot tell which regions may experience large changes, nor where impacts might be modest, except that warming will be most pronounced at high northerly latitudes in winter and in the interior of the continents. Also, the hydrological cycle will intensify, which implies more precipitation and more rapid evaporation. Both flooding and drought will probably occur more frequently. There is now clear evidence that the frequency of intense precipitation has increased during the last few decades in some regions.

The climate convention prescribes that the ultimate goal is to stabilize the concentrations of greenhouse gases in the atmosphere, but no agreement has been reached yet about the level to be aimed for. The European Union has agreed that the change of the global mean temperature should not exceed about 2 degrees C. This in turn means that stabilization of carbon dioxide concentration must be achieved at a level not exceeding 60–80 per cent of the pre-industrial level, i.e., between 450 and 500 parts per million (ppmv) (cf. table 1),

Table 1 *Radiative forcing and temperature changes at the time of stabilization at alternative carbon dioxide concentration levels.*

Level of stabilisation (ppmv)	*Radiative forcing (W/m^2)*	*Temp change lower bound degrees C*	*Temp change central value degrees C*	*Temp change upper bound degrees C*
450	3.6	1.2	2.1	3.6
550	5.0	1.7	2.9	5.2
650	6.2	2.1	3.5	6.4
750	7.1	2.5	4.1	7.4

Note: It has been assumed that emissions of methane, nitrous oxide and sulphur dioxide until 2100 will be as given by the IPCC Scenario IS92a and thereafter remain constant. The range of sensitivity of the climate system is assumed to be between 1,5 and 4,5 degrees C for doubling the atmospheric carbon dioxide concentration.
Source: IPCC Technical Paper (TP) III (1997). 'The stabilisation of greenhouse gas concentrations in the atmosphere', World Metereorological Organisation. Geneva.

even if the sensitivity of the climate system would be in the lower part of the range of uncertainty as given above. The increase in carbon dioxide levels so far has been about 30 per cent (pre-industrial concentrations were about 280 ppmv and present concentrations are about 360 ppmv). Global emissions will have to start declining quite soon in order to reach the goal of stabilization at the prescribed level toward the end of next century. Nature puts a bound on the magnitude of emissions during the next century, the magnitude being a function of the concentration level aimed for (see further below). This magnitude can be deduced with some confidence.

The uncertainties of the scientific findings so far imply that the issue of a future change of climate should be considered as an issue of risk. It is in that context important to recall the fact that the forcing of the climate system due to increased concentrations of greenhouse gases will be with us for a long time once it has occurred, even if steps were taken to reduce greenhouse gas emissions rapidly. The uncertainties shown in table 1 are indeed troublesome, but the risk is not diminished due to uncertainties. It just becomes more difficult to assess.

It is finally of interest to illustrate the change in the global mean surface temperature as deduced with the aid of one of the most advanced climate models.[2] Figure 3 shows the changes as a function of time until 2050, assuming that the emissions of carbon dioxide increase by 1 per cent per year (which is close to the increased forcing according to the medium IPCC Scenario, IS92a, also including projected emissions of other greenhouse gases). An experiment has also been made which includes emissions of sulphur dioxide and thus the formation of aerosols. It is important to emphasize that this is the result of a single run with a particular climate model and should not be considered as a prediction of the future change of climate.

[2] Mitchell, J., *et al.*, 1995, IPCC, Second Assessment Report. Vol. I, 1996.

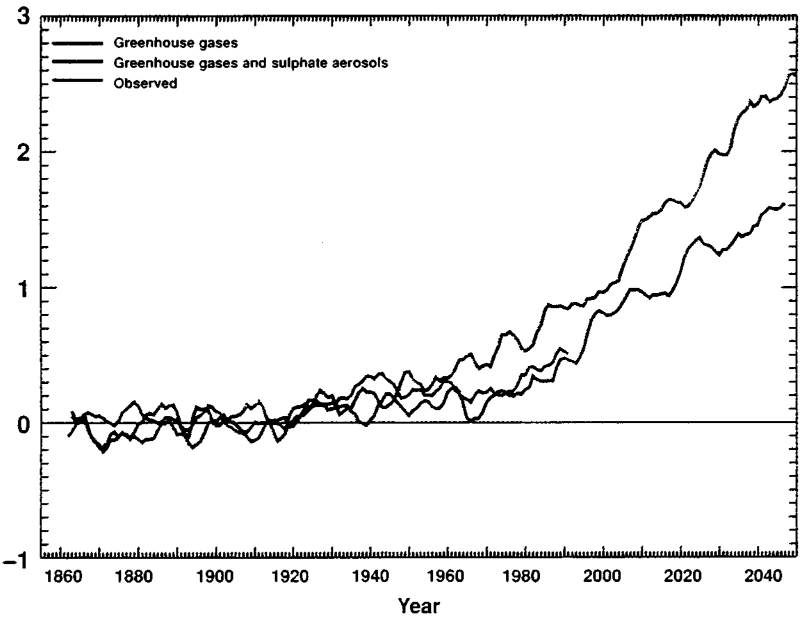

Figure 3 *An example of projected changes of the future global mean temperature due to changing concentrations of greenhouse gases only (upper curve) and if including the influence of aerosols (lower curve). The observed changes until 1990 are also shown. (cf. IPCC/SAR 1995 a)*

Impacts of climate change

Because of the limited possibilities to project more precisely the likely geographical pattern of a climate change, it is difficult to assess its impacts accurately. The IPCC assessments have therefore concentrated on analyses of the sensitivity of different segments of society to prescribed climate changes of the magnitude that might be expected. Such analyses should be developed nationally, since thorough knowledge about the environmental, societal, and economic characteristics of the country concerned is required. Some general comments are, however, of interest in the present context.

Damages, in some cases possibly benefits, due to climate change much depend on how the present occurrence of extreme events, such as storms, heat waves, droughts, floods, frosts, etc. might change. Higher spatial resolution of climate models is required to adequately deduce theoretically such features of a future change in climate so that more precise conclusions can be drawn from the model experiments that have been carried out so far.

Observations during the last few decades indicate, however, that storms and floods seem to have increased in some areas, although probably not globally. This also confirms that the risk from damage associated with global climate changes varies from one region to another.

The observed increase of damages in recent decades due to extreme weather events has been noted by the insurance industry. It is well known that major losses have been experienced in the Caribbean region and in the

Pacific. As a matter of fact the insurance premiums have become very high in some regions with the consequence that few can afford to pay for insurance. It is obviously difficult for the insurance industry to deal with future climate change. To use the statistics of what has happened in the past is no longer a viable approach. Some observed changes may be a result of increasing human-induced forcing of the climate, but this cannot be concluded in any firm way.

It is also possible to deduce reasonably well the increased probability of high temperatures during heat waves for a given change in the temperature during the warmest season and also to estimate the likely associated increase of morbidity and mortality. There are several assessments of this kind (particularly for major cities in the United States) that are of interest.

Similarly, the increasing threats to small islands and coastal regions because of increasing sea levels can be evaluated reasonably well. Most of the damage is caused by flooding associated with storms and hurricanes. It is to be noted that the risk of damage increases, even if such extreme events did not become more frequent.

The most important question is, however, to what extent agriculture and forestry might be seriously affected. Some regions in the sub-tropics have experienced extended periods of drought during the last few decades. Even if it is not possible to ascribe these changes in climate to human emissions of greenhouse gases, valuable information about the sensitivity of the agricultural industry to change in climate can be deduced. Agriculture can adapt to some extent by changing crops and management practices, but adequate precipitation still remains as an important prerequisite even though higher carbon dioxide concentration in the atmosphere reduces the water losses during photosynthesis.

Model projections of future changes in regional climate have been used in order to determine how the present distribution of forests on earth might change. Even if the detailed changes deduced in this way are uncertain the statistics that can be derived is of considerable interest. The IPCC concludes that 'as a consequence of possible changes in temperature and water availability under doubled equivalent carbon dioxide equilibrium conditions, a substantial fraction (a global average of one-third, varying by region from one-seventh to two-thirds) of the existing forested area of the world will undergo major changes in broad vegetation types, with the greatest change occurring in high latitudes and the least in the tropics'.

In conclusion, we are not yet able to tell more precisely how 'dangerous' a human-induced climate changes will be, nor will it be possible to deduce if such changes will come about within decades or if they will be a slower and less threatening process. The risk must, however, not be ignored.

Mitigation and/or adaptation?

This question is basically not an issue of either or. The key question rather becomes: How much of a climate change could be accepted and adapted to, and what mitigation efforts should be aimed for. The answer is not exclusively dependent on an economic judgement, but the question also raises fundamental social and ethical issues.

We need of course to find out what impacts of global climate change are serious enough to justify concerted actions by the global society. However, climate varies naturally and the societal structures of our society have been built with an implicit consideration of such variations. It is robust for moderate changes in the environment. It is, however, now becoming possible to distinguish a human-induced climatic trend from this natural variability. But what does the expression 'moderate changes' really mean? And further and most importantly, we can not exclude surprise changes if the biogeochemical balances that have been established over geological times are being disturbed substantially as may well be the case in the future.

It is difficult to assess likely net damages caused by a climate change. As a matter of fact for many people the signals of such change are still not clear enough to consider a future human-induced climate change to be a serious threat. On the other hand, waiting for clear signals in order to give broad public acceptance to the threat, may take a long time and increase the costs for mitigation because necessary actions may have to be more far-reaching and then be taken more quickly. Also, the fact that both the natural environmental and the socio-economic systems change only slowly due to their inertia implies that long-lasting efforts are needed.

Because impacts cannot yet be estimated accurately, traditional cost–benefit analysis is hardly possible at this stage because of the need to assess future damages reasonably well. Setting the goals for mitigation will therefore for some time have to be based largely on qualitative judgements with due regard given to public opinion. *Cost estimates are, however, important for the choice of strategies and to reach agreement on how to share the burdens within countries, between countries, and between generations.*

Because of all these inherent uncertainties the IPCC points out that 'a prudent way to deal with climate change is through a portfolio of actions aimed at mitigation, adaptation, and improvement of knowledge. The appropriate portfolio will differ for each country. The challenge is not to find a solution for the best policy today for the next 100 years, but to select a prudent strategy and to adjust it over time in the light of new information.' Also, 'The scientific literature indicates that *significant "no regret" opportunities are available in most countries and that the risk of aggregate damage due to climate change, consideration of risk aversion, and application of the precautionary principle provide rationales for action beyond no regret.*'

Policies and measures

The IPCC has prepared an extensive summary of available technologies, policies and measures for mitigating climate change.[3] It provides an overview and analysis of technologies and measures to limit and reduce greenhouse gas (GHG) emissions and to enhance GHG sinks under the Climate Convention, FCCC. The paper focuses on actions by developed countries, while noting information as appropriate for use by developing countries. They are examined over three time periods, with a focus on short-term (present to 2010) and medium-term (2010–2030), but also

[3] IPCC Technical Paper (TP) I, 1996. 'Technologies, policies and measures for mitigating climate change', World Meteorological Organisation, Geneva.

including some discussions of long-term (e.g., 2050 and beyond), possibilities and opportunities.

The technical paper includes discussions of technologies and measures that can be adopted in three end-use sectors (commercial/residential/institutional buildings, transportation, and industry), in the energy supply sector, and in the agriculture, forestry, and waste management sectors.

It is important to recognize the differences between technical, economic and market potentials for mitigation defined as

Technical Potential The amount by which it is possible to reduce GHG emissions or improve energy efficiency by using technology or practice in all applications in which it could technically be adopted, without consideration of its costs or practical feasibility.

Economic Potential The portion of the technical potential for GHG emissions reductions or energy efficiency improvements that could be achieved cost effectively in the absence of market barriers. The achievement of economic potential requires additional policies and measures to break down market barriers.

Market Potential The portion of economic potential for GHG emissions reductions or energy efficiency improvements that currently can be achieved under existing market conditions, assuming no new policies and measures.

Such a distinction has not always been made in the ongoing debate, which has lead to unrealistic claims with regard to the possibility of quickly achieving substantial reductions in emissions. On the other hand, Technical Paper 1 clearly shows that there are many possibilities to do what may be required and, to begin with, at no or modest net costs. Also, measures taken may serve other purposes. Such so-called 'win–win' situations should be taken advantage of. Close analyses are needed to clarify the situation for individual countries, since the opportunities vary considerably.

Examples

Residential, commercial, and institutional buildings sector

It is today possible to construct houses that require only a small fraction of present needs for heating. This includes the use of, e.g., specially designed walls and windows, the employment of heat exchange systems for ventilation. The technical feasibility has been proven, but costs need to be further reduced. The potential for the future is large.

Many specific equipment, e.g., household appliances, that reduce the need for energy are available already today in many cases at competitive prices. The major administrative, institutional, and political barriers in implementing market-based programmes for residential and commercial building equipment are:

- difficulties in improving integrated systems,
- the need for, and shortage of, skilled persons capable of diagnosing and rectifying systems problems,

- the fact that energy users are often not those responsible for paying energy bills, creating a barrier to increased efficiency,
- the need to structure incentives so that intervention in buildings aims at achieving all cost-effective energy efficiency measures,
- the need to create institutional structures for market-based programmes to work effectively,
- perception (or reality) of cross substitutes and related unfairness of expenditures.

Transport sector

About 20 per cent of today's emissions of carbon dioxide come from the transport sector. Its relative role is expected to increase substantially in the future, particularly because of the expansion of aviation. Fossil fuel use in this sector may double within 25 years and triple before the middle of the next century.

It is already technically feasible to reduce gasoline consumption substantially. Rapid changes are difficult to achieve because of the infrastructure that has developed during the twentieth century and is still expanding rapidly. There are, however, several social and environmental costs associated with road transport at local, regional, and global levels that should be addressed simultaneously. Market instruments such as road-use charges can be used to reflect many of these costs, especially those at the local and regional levels. These instruments might also contribute to greenhouse gas mitigation by reducing traffic.

Changes in urban transport infrastructure, to reduce the need for motorized transport and shift demand to less energy intensive transport modes, may be the most important element of a long-term strategy for greenhouse gas mitigation in the transport sector.

Industrial sector

During the past two decades, the industrial sector fossil fuel carbon dioxide emissions of most developed countries have declined or remained constant while their economies have still grown. The present emissions from this sector contribute almost 50 per cent of the emissions, of which the industrialized countries are responsible for about three quarters. It is estimated that these countries could still lower their industrial sector emissions by more than 25 per cent relative to 1990 levels, by simply replacing existing facilities and processes with the most advanced technological options currently available (assuming a constant structure for the industrial sector). If this upgrading occurred at the time of normal capital stock turnover it would in most cases be cost effective.

Energy supply sector

Energy consumed in 1990 resulted in the release of 6.0 Gt. C (in 1996 6.5 Gt.). About 72 per cent of this energy was delivered to end users, the remainder was used in energy conversion (particularly waste of heat in the process of generation of electricity) and distribution. It is technically possible to realize deep emissions reductions in the energy supply sector in step with the normal timing of investments to replace infrastructure and equipment as it wears out or becomes obsolete.

The efficiency of electricity production can be increased from the present world average of about 30 per cent to more than 60 per cent sometime between 2020 and 2050. Presently the best available coal and natural gas plants have efficiencies of about 45 per cent and 52 per cent respectively. While the associated costs to achieve these efficiencies will be influenced by numerous factors, there are advanced technologies that are cost effective, comparable with some existing plants and equipment. The combination of electricity generation with the utilization of the waste heat for local (or regional) supply of heat for the residential/commercial/institutional sector provides many opportunities for saving energy, particularly in temperate and cold climates.

Historically, the energy intensity of the world economy has decreased, on average, by 0.5–1 per cent per year, largely due to technology performance improvements that accompany the natural replacement of depreciated capital stock. Improvements beyond this rate are unlikely to occur in the absence of deliberate efforts.

Agricultural sector

Agriculture accounts for about 20 per cent of the anthropogenic greenhouse gas emissions, primarily due to the emissions of methane and nitrous oxide, but only about 5 per cent of the anthropogenic carbon dioxide emissions come from agriculture. Considerable reductions of greenhouse gas emissions from the agricultural sector can be accomplished, primarily from offsets by bio-fuel production on land currently under cultivation. Reduction of anthropogenic methane production is primarily an issue for developing countries. The need for systems analyses by country for determination of possible reductions of greenhouse gas emissions from this sector is apparent

Forest sector

High- and mid-latitude forests are currently estimated to be a net carbon sink of about 0.5 + / −0.2 Gt. C / yr. Low-latitude forests, on the other hand, are estimated to be a net source of 1.6 + / − 0.4 Gt. C / yr., caused mostly by clearing and degradation of forests. These sources and sinks may be compared with the carbon release from fossil fuel combustion (6.0 Gt. C / yr. in 1990). It is further to be noted that emissions due to fossil fuel burning represents injection of carbon that has been buried in the ground for millions of years, while increases and decreases of carbon in forests should be viewed as redistribution of carbon between terrestrial reservoirs. This implies that the net influence on atmospheric carbon dioxide concentrations will remain rather limited in a long-term perspective, because of the limited amounts that are available for rapid exchange between these reservoirs. Still, it is obviously important to halt deforestation. Governments in a few developing countries have instituted measures to achieve that.

Wood residues are used regularly to generate steam and/or electricity in

Table 2 *Primary energy sources, 1990 (IPCC, 1996)*

Primary energy	*Percentages*	
Fossil fuels		75.3
Oil	33.3	
Gas	18.4	
Coal	23.6	
Nuclear		4.9
Hydro		5.5
Biomass		14.3

most paper mills and rubber plantations, and in specific instances for utility electricity generation.

Solid waste and wastewater disposal
An estimated 50–80 Mt. of methane was emitted by solid waste disposal facilities and wastewater treatment facilities in 1990. Although there are large uncertainties in such emissions estimates for a variety of reasons, overall emissions levels are projected to grow significantly in the future.

Technical options to reduce methane emissions are available and, in many cases, may be profitably implemented, e.g., by paper recycling, composting, and incineration and also through methane recovery from landfills and wastewater, which in turn may be used as an energy source and be cost competitive with other energy alternatives.

Mitigation of carbon dioxide concentrations in the atmosphere
There is of course a need to consider all human induced emissions of greenhouse gases when deciding on a policy for mitigation. Nevertheless, the use of fossil fuels and the associated changes of the turnover of carbon in nature necessarily come in the forefront of discussions about preventive measures because of its dominating role as a greenhouse gas.

Since about 75 per cent of the total energy used in the world is provided

Table 3 *Global fossil energy reserves and resources, their carbon content, energy potentials by 2020–2025, and maximum technical potentials*

	Consumption (1860–1990)		*Consumption (1990)*		*Reserves identified potentials by 2020–2025*		*Resource base maximum potential*	
	EJ	*Gt.C*	*EJ*	*Gt.C*	*EJ*	*Gt.C*	*EJ*	*Gt.C*
Oil								
Conventional	3,340	61	128	2.3	6,000	110	8,500	160
Unconventional	–	–	–	–	7,100	130	16,100	300
Gas								
Conventional	1,700	26	71	1.1	4,800	0	9,200	140
Unconventional	–	–	–	–	6,900	100	26,900	400
Coal	5,200	131	91	2.3	25,200	640	125,000	3,170
TOTAL	10,240	218	290	5.7	50,000	1,050	186,000	4,170

Note: EJ = Exajoule, Gt.C = Gigaton of Carbon (deduced from IPCC, 1996)

Table 4 *Accumulated emissions 1990–2050 and 2050–2100 for the IPCC scenarios IS92 a–f, and for stabilization scenarios at carbon dioxide concentrations of 450, 550, 650, and 750 ppmv.*

Scenarios		*Accumulated Emissions, Gt.C*		
		1990–2050	*2050–2100*	*1990–2100*
IS 92 c		500	270	770
IS 92 d		530	450	980
IS 92 b		630	800	1430
IS 92 a		660	840	1500
IS 92 f		770	1060	1830
IS 92 e		820	1370	2190
Stabilize at	450 ppmv	420 + / − 20	220 + / − 30	640 + / − 50
	550 ppmv	520 + / − 30	410 + / −30	930 + / − 60
	650 ppmv	580 + / − 40	530 + / −40	1110 + / − 80
	750 ppmv	630 + / − 40	630 + / −40	1260 + / − 80

by burning oil, gas, and coal, mitigation of climate change necessarily implies a reconsideration of the long-term future energy supply in the world. The prime sources of energy today are given in table 2.

It is further essential to consider our knowledge about the amounts of fossil fuels used so far and the reserves and resources for the future (see table 3). It is of course difficult to provide accurate estimates of resources, since their magnitudes depend on future costs for extraction. The data in table 3 are therefore uncertain, but still of interest.

The numbers in table 3 should be compared with those in table 4, that show the estimated accumulated emissions for the IPCC emission scenarios IS92 a–f, assuming no mitigation efforts, but different assumptions about changes of world population, GDP growth, carbon intensity of primary energy sources, and efficiency of energy use. The central estimates (a and b) are most relevant because of more modest increases of productivity and the use of the central UN estimate for the increase of world population. The lower part of the table shows the estimates of accumulated emissions that would be ‘permissible’, if stabilization at alternative concentration levels were prescribed (Figures 4 and 5).

The emissions given in table 4 are total emissions, i.e. they include both those due to fossil fuel burning as well as deforestation and changing land use in the future. During the period 1860–1990 deforestation has amounted to 100 + / 30 Gt. C. The IS92 scenarios assume accumulated emissions 1990–2050 to be 25–65 Gt.C and during the second half of the twenty-first century to 5–30 Gt.C. As seen these numbers are comparatively small but of course uncertain, since we know little about the future rate of deforestation and changing land use. The ‘permissible’ emissions from fossil fuel burning are obtained by deducing the estimated emissions due to deforestation and changing land use, as given above or derived otherwise, from the numbers given in table 4.

Table 3 shows that the total potential future emissions of carbon dioxide by burning *conventional oil and gas reserves* is estimated to about 180 Gt.

Even if utilizing gradually the *total resource base of conventional oil and gas* during next century, it seems not likely that more than about 500 G will be emitted. This is well below the permissible emissions during next century both in case of no mitigation (central scenarios IS92*a* and *b*) as well as stabilization, even at a level as low as 450 ppmv and certainly so for less stringent stabilization targets. A major change of the global climate would not come about if only of the conventional oil and natural gas reserves and resources were exploited, but certainly so if the use of coal as a primary energy source would continue to increase as seems most likely. There are large amounts of carbon in the form of coal as well as unconventional resources of natural gas and oil. A good number of major coal fields in the world have been established and produce coal at competitive prices.

About 60 per cent of todays carbon dioxide emissions stem from the burning of oil and gas. Thus in anyone of the IS92 scenarios of no intervention (except IS92c), it is likely that conventional oil and gas will start to become scarce towards the middle of next century unless coal or unconventional fossil fuel resources are exploited at an increasing rate. What will happen in reality will of course critically depend on the costs for their extraction. In the light of the major total resources that most likely exist, there is a serious risk that fossil fuels will be increasingly used throughout the twenty first century, if no efforts of mitigation will be undertaken.

It becomes clear that a major change of the global energy supply system will have to be under way towards the middle of next century, but sooner the more of a threat that a global climate change represents. Other primary energy sources will have to replace them gradually. To avoid a global change of climate, above all coal and unconventional fossil fuels must not become the prime source of energy. Nuclear energy is of course not a renewable energy resource but may play a role for some time. Hydro power and wind power will not suffice. In the long term, solar energy and biomass will have to become major components of the future global supply system.

The crucial question therefore becomes: Which is the optimal time and rate for transition into the use of renewable energy sources in the development towards a sustainable world? We need to judge the seriousness of future damages brought about by a climate change, in comparison with the global social, economic, and political difficulties that may arise if basic supply systems are changed more rapidly than the market would require in order to prevent such a change. The major differences between countries in the world must also be taken into consideration. It is of course not possible to answer this question in definite terms, but the IPCC analysis shows that much can be done at modest costs. It should also be recalled that a gradual approach is most likely less costly than later crash mitigation programs.

Concluding remarks concerning the socio-economic dimension of the climate change issue

A brief summary has been given above of what we know and what we do not know about the global climate system, its response to human

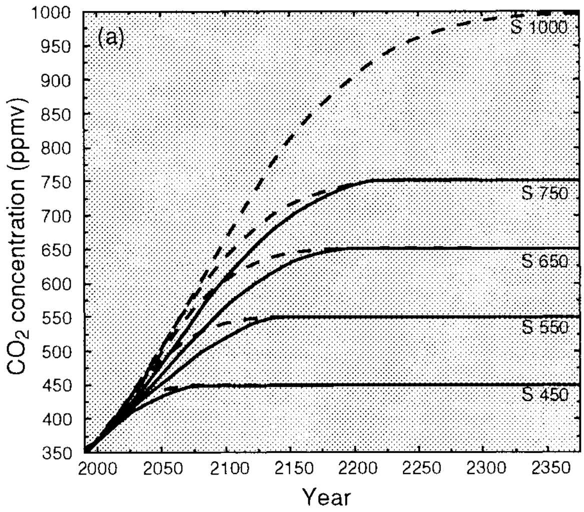

Figure 4 *Alternative concentrations scenarios for stabilization of atmospheric carbon dioxide at 350, 450, 550, 650, and 750 ppmv. The 'new' scenarios follow the scenario IS1992A (business-as-usual) during one or a few decades in order to permit the change over into satisfying the restrictions as required to reach the prescribed stabilization levels.*

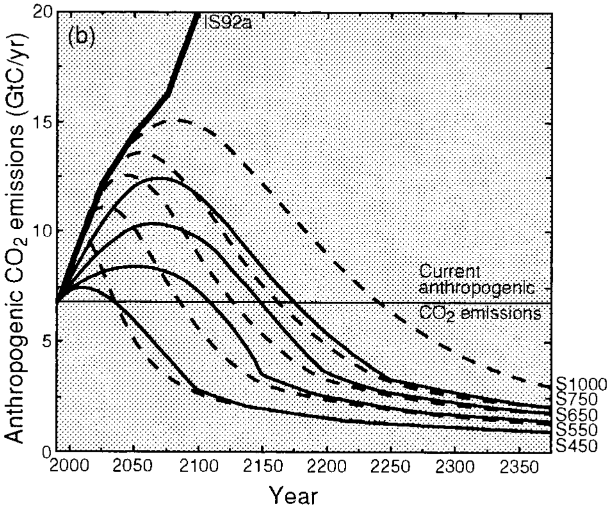

Figure 5 *Emissions scenarios for stabilization of atmospheric carbon dioxide concentrations in accordance with the scenarios as given in figure 1.*

emissions as well as how the socio-economic system is influenced by climatic changes and the changes that may be necessary to limit a climatic change. It is increasingly being realized that we need to look at the dynamics of this total interacting human–environmental system. Lately, so-called integrated models have been developed in order to do so. These models yield interesting results about these interactions, but they must still be considered to be in their infancy for a number of reasons.

> There are few possibilities to validate such models with the aid of past observed changes. Actually few have tried to do so, presumably because of insufficient data. This implies that the sub-models, which together constitute an integrated model, must be tested separately, which is not easy either. Further, it is well known from the development of global climate models that new problems arise when coupling sub-models together and in that context relaxing the constraints that necessarily have been prescribed when experimenting with the sub-models separately.
>
> Major simplifications of the different sub-models must be introduced, not the least because of the fact that some such models are much more sophisticated than others and cannot be used in an integrated model without simplifications. For example, climate models that are presently employed, are very much simpler than those used in deriving the spatial patterns of global climate change. They can be and often have been calibrated against more advanced, so-called global circulation models, but still they do not provide spatial patterns of climate change.
>
> Both the environmental system and the socio-economic system are partly stochastic in their nature, a fact that often is not sufficiently recognized in building integrated models. It is therefore most essential to analyse what this may imply with regard to the stability of the results that are derived with the aid of integrated models. Few integrated models have been exposed to random variations of the prescribed coefficients that are introduced to quantify the different processes that interplay in the rather simple integrated models. It is, for example, essential to explore the implications of the rather wide range of uncertainty of the sensitivity of the global climate to human disturbances, that still prevails. Few details of the results from experiments with integrated models are as yet reliable. As a matter of fact, the most important task at this stage of development is to establish which results are robust for variations of assumptions and which are not.

For the reasons listed above, it is important to attempt to formulate more general questions. We know that the characteristic time scales of the climate models, that we are concerned with, range from decades to one or a few centuries. Short-term variations of the socio-economic system are therefore in themselves of secondary importance. How then to deal with these statistically in order to grasp their possible role in the long-term perspective? How to include the development of regional and temporary crises in the world (e.g., another and more extended oil crisis), that we know have been of fundamental importance in the past? They represent an other kind of uncertainty. This implies that focus should be on the inertia and robustness (or lack of robustness) of the socio-economic system. In the context of climate change, the inertia of the global energy supply system (or rather the relative role of its components now and in the future)) and its transformation into one largely based on primary sources other than fossil fuels come into the forefront.

The IPCC has emphasized that cost-benefit analyses are still premature, because of the fundamental difficulties that arise in attempting to assess future damages and the discount rate to be used in such analyses extending over time periods of many decades to a century. The derivation of cost estimates for mitigation *and* adaptation should then rather be put in focus and the analyses of possible multiple benefits that may accrue from some measures ('win–win situations'). The study of economical path ways (as a function of time) towards stabilization of carbon dioxide concentrations in the atmosphere is obviously of interest.

Socio-economic models have been used to estimate total costs for reaching stable carbon dioxide concentrations and the analyses yields values of 1–2 per cent of GDP for developed countries and significantly more for developing countries. Figures of this kind can be misleading rather than helpful, if not put in a more general development perspective. It is, for example, generally expected that GDP for the world will increase substantially during coming decades (a figure of 2 per cent annually is often quoted). Accordingly an annually increasing amount of perhaps 0.1 per cent of GDP that may be needed to address the climate change issue is in that perspective small, even if it may amount to an additional 30–40 billion dollars annually for the world as a whole. This does, however, not mean that it is easy to initiate such long-term development towards a sustainable world. Considerable structural changes within countries will be required. The 'losers' in such a process are often rather easy to identify, while the 'winners' that will be able to take the lead in the renewal process that is required have often not yet emerged.

It is, however, important to recall that cost estimates should not be considered as an extra burden to be financed over and above all other needs in society, but rather be used as a guide in assessing what to chose between alternative development paths in general for the future. It is just too easy for society to follow a path in the future not much different from what has been the main route forward in the past. Changes seem now to be required, but the choices are not obvious and easy.

It must finally be recognized that political decisions on an issue such as the climate change issue will not be taken exclusively based on quantitative information as provided by the scientific assessments outlined above. Social and political values, not the least concerning equity, come into play as has so clearly been seen in the past. This will certainly also be the case in the future.

Addendum

The third Conference of Parties to the Framework Convention on Climate Change took place in Kyoto in December 1997. A few comments on the outcome of that meeting in the light of the summary of the issue as given above may be of interest.[4]

An agreement was reached on targets and timetables. While no restrictions were introduced for Non-Annex 1 (developing) Parties, Annex 1

[4] See also Bert Bolin; 'The Kyoto negotiations on climate change: a scientific perspective', Science, **279** (16 January 1998), 330–331.

(developed) Parties jointly agreed to reduce their emissions by an amount that would yield a reduction of the radiative forcing by about 5 per cent by 2010 as compared with 1990. The major emitters US, EU and Japan took on reductions of 7, 8, and 6 per cent respectively. Russia and Ukraine, on the other hand, were permitted to return to levels of emission equal to those in 1990, in spite of the fact that presently they had reduced their emissions by 25–30 per cent. It should also be noted that Annex 1 Parties by 1995 already had decreased their emissions by about 5 per cent primarily because of the reductions in countries in economic transition and the agreement thus did not imply any further reductions, but a modified distribution amongst them. This seemingly rather *ad hoc* distribution of future responsibilities amongst Annex 1 Parties was obviously an outcome of political negotiations.

As a matter of fact this agreement would change the rate of increase of carbon dioxide in the atmosphere during the next 15 years very little, even if the agreements were adhered to strictly, which may not necessarily be the case. As a matter of fact, judging from the rather short-sighted attitudes from many delegations, ratification of the agreed protocols may well take a good number of years.

The goal set in Kyoto is far from what is aimed for in Article 2 of the Convention, i.e., 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. Obviously the inertia of the climate system was not fully appreciated by the delegates in Kyoto. The agreement implies that the increase of greenhouse gases will not accelerate during the next 15 years, but rather be steady at about 1.5 ppmv per year. It is very clear that, although it is generally accepted that increasing greenhouse gas concentrations will lead to a change of the global climate, politicians do not feel that actions are urgent. I expect, however, that our ability to describe the magnitude and consequences of a global change of climate will improve substantially during the next 5–10 years and one may wonder, if the agreement may have to be renegotiated well before 2010.

Although it is important to set targets and timetables, the fundamental problem of climate change cannot be settled that simply. It is essential that measures to deal with the climate change issue are cost effective. Both regulatory measures and economic instruments can be used, but the IPCC has emphasized that economic instruments such as emissions trading or carbon taxes can substantially reduce the costs of achieving a given target. The Kyoto conference is a first step toward the introduction of economic instruments to achieve given targets. The emissions targets as briefly described above can be seen as an invitation to trade reduction units, particularly between OECD countries and countries in economic transition. How this will be achieved remains to be seen. The next Conference of Parties in Buenos Aires in November 1998 will consider this issue and attempt to resolve it.

An Australian victory at Kyoto?

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Professor Bolin's paper is a valuable summary and overview of the state of knowledge with respect to many of the dimensions of the 'the climate change issue'. His remark that cost estimates for greenhouse gas mitigation 'can be misleading rather than helpful, if not put in a more general development perspective' is an important caution for economists seeking to inform public debate. It can be illustrated by experience here in Australia. In the lead-up to the Kyoto meeting in December 1997 the Australian government argued for differentiated mitigation targets for the Annex 1 nations, and that, among such, Australia would suffer an unfair, and large, cost burden if uniform targets were adopted. Its position was largely based on applied general equilibrium modelling work done by the Australian Bureau of Agricultural Resource Economics, ABARE, a research agency primarily funded by government but also in receipt of funding from fossil fuel interests. This work was extensively reported in the media, predominantly in terms of it providing authoritative and definitive support for the government's position. In its own reports, ABARE did little to put its results 'in a more general development perspective', or indeed in any proper perspective. For example, in a 1996 ABARE paper modelling results were reported where uniform mitigation targets gave rise to reductions in per capita GNE, compared to business as usual, of 0.10 per cent for the US and 0.37 per cent for Australia. With Annex 1 national targets set so as to equalize per capita GNE losses, while producing the same total Annex 1 outcome, the loss for Australia was reduced to 0.12 per cent. These results, the paper concluded, supported the case for differentiated targets for Annex 1 nations, such that Australia would do less mitigation than, for example, the US. The paper did not note that the measurement errors associated with GNP/GNE numbers are of the same, or greater, order of magnitude as these differences.

Many might, anyway, regard a once-off loss of 0.25 per cent, or even 0.50 per cent, of per capita GNE as a small cost in the context of high-income Annex 1 nations. In an article published in the influential daily newspaper *The Australian Financial Review* (7/3/97), two senior ABARE economists sought to rebut the view that the cost to Australia of uniform targets would be 'insignificant' by reporting 'ABARE estimates that Australia would suffer a net present value loss of 3.5 per cent of gross national expenditure'. Elsewhere this was translated into money sums of thousands of dollars per Australian household. In a letter published three days later in *The*

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Australian Financial Review, I inferred from this article that whereas the loss was the discounted value of the cumulative annual losses up to 2020, it was being expressed as a percentage of one year's GNE. This is consistent with ABARE results such as those cited above, and was not disputed by the article's authors. In that case, the annual 'welfare cost' estimated by ABARE was equivalent to each Australian adult foregoing two small glasses of beer per week.

My 'contribution' here, and that of others seeking to provide some perspective on these numbers, did not affect the general mainstream perception that it was a matter of vital national interest for Australia to secure special treatment at Kyoto. In the event, the Kyoto Protocol did afford Australia special treatment. The Australian media overwhelmingly reported the Kyoto outcome as a 'victory' for the Australian government. In *The Australian Financial Review* 12 December 1997, for example, the main front page headline was 'Australia's greenhouse triumph'. The victory/triumph actually involved two 'wins'. First, in that Australia was set a mitigation target allowing it annual emissions in the commitment period 8 per cent larger than in 1990, whereas with the exception of Iceland (10 per cent increase) and Norway (1 per cent increase) all other Annex 1 parties are to stabilize at or reduce on 1990 levels. Second, in that the Protocol allowed Annex 1 parties 'for whom land use change and forestry constituted a net source of greenhouse gas emissions in 1990' to include land use change based emissions in 1990 in the base to which the mitigation target related (para. 7 article 3). Australia is such a party, and the inclusion of this provision was apparently at its instigation and involved a personal success for its Environment Minister based on an ability to stay awake for a long time. It is currently understood that since 1990 land use change based emissions in Australia have been falling. This double 'victory' is currently taken to imply that Australian industry will face relatively little incentive to 'bias' technological change away from fossil fuel use. To the extent that the rest of Annex 1, where the direction of global technological change is set, does move in the direction of reduced fossil fuel intensity, Australian industry is likely to suffer a long-term loss of competitiveness. This could itself imply national income losses of similar magnitude to those projected to follow from having agreed to cut emissions in line with the major Annex 1 nations. The equivocal nature of Australia's 'victory' in this respect has been noted by some environmentalist commentators, but has received virtually no attention in the mainstream media.

Of course, what Australia does, or does not do, about mitigation will have very little impact on the future course of global emissions (similarly for Norway and Iceland). This was, no doubt, the major reason why Australia was able to secure its 'victory'. Were this not the case, one imagines that a curious feature of the treatment that Australia sought, and got, would have received more attention. As exemplified by the ABARE modelling work noted above, the case for Australia being a high abatement cost nation was based on analyses which did not take account of land use changes. Abatement by reducing land clearing and/or re-afforestation is generally understood to be low cost in Australia.

Was the Kyoto outcome a 'victory' for the world as a whole? If one accepts the thrust of Professor Bolin's paper, and given realistic expectations, the answer would appear to be 'yes', subject to caveats about matters, such as compliance enforcement and the details of emissions trading, that the Protocol leaves to be worked out. It is Bolin's judgement, in my view sound, that 'a major change of the global energy supply system will have to be underway by the middle of the next century', with solar energy and biomass as major components of energy supply, and that 'a gradual approach is most likely less costly than later crash programs'. The Annex 1 nations have committed to collective mitigation, and the major, in terms of technological innovation, players have committed individually. Economists will look with favour on the provisions allowing emissions trading, joint implementation, bubbles and banking, though it might be argued that some of these features have the potential to weaken the forcing of technology change, and for this and other reasons many environmentalists are suspicious of emissions trading particularly. Even assuming target attainment on the part of the Annex 1 parties, the fact that the other parties have not entered into any mitigation commitments means, at least, that global mitigation is not assured. This also gives rise to the possibility of non-ratification by the US, which could give rise to problems not only in terms of action in the US but also in regard to the provision that the Protocol takes effect only if ratified by parties accounting for 55 per cent of total Annex 1 emissions. It would have been unrealistic, and inequitable, to have expected developing nations to adopt commitments of the type adopted by the Annex 1 parties. However, developing nation commitments in terms of currently non-binding ceilings on per capita emissions, at say the European level, might have been acceptable and might have satisfied the US legislative branch.

In any event, given the background provided by Professor Bolin, it seems clear that failure to reach agreement at Kyoto would have to have been judged a 'defeat' for the global community. That this was avoided is likely to be a more solid basis for judging the outcome a victory for Australia than the special treatment that Australia secured. If Australia does not participate in the technological change that it is to be hoped that Kyoto initiated, its 'free ride' may turn out to be largely illusory.

Global climate change: the challenges for development policy

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Introduction

Professor Bolin aptly summarizes the key issues, threats, and unknowns the global community is facing with regard to anthropogenic climate change, drawing on the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) which was produced under his chairmanship (IPCC, 1996). He reiterates what is now the belief of a majority of scientists, that 'the balance of evidence suggests that there is now a discernible human influence on the global climate'. Professor Bolin remains cautious, though, about the policy implications of this finding. He simply points out the likely impacts of climate change, describes available mitigation technologies, and rather generally recommends 'a portfolio of actions aimed at mitigation, adaptation and improvement of knowledge'.

It is tempting to compare this recommendation, and the findings of the IPCC Second Assessment Report in general, with the reality of the recently agreed Kyoto Protocol. The emission cuts agreed in Kyoto do not come anywhere near those that will ultimately be needed to stabilise the atmospheric concentration of greenhouse gases at a safe level. Nevertheless, Kyoto produced a better Protocol than many observers have expected beforehand. We have to remember that climate change is a long-term problem. Many analysts now agree that the most desirable global emissions path is hump-shaped (with the shape of the hump still under debate): Emissions can initially continue to rise (particularly in developing countries), but radical cuts have to follow in the medium term. Compared to such a time path, the Kyoto target is more or less on track, provided the Protocol is ratified and implemented as planned. Arguably, in Kyoto the process was more important than the actual targets, and this process has been set in motion – including provisions to address the problem in a cost-effective way by exploiting differences in abatement costs between participating countries.

What does the Kyoto Protocol, what does global climate change, mean for development policy?

Greenhouse gas mitigation

The Second Assessment Report makes clear that in the long run the stabilization of atmospheric greenhouse gas concentration will only be

The interpretations and conclusions in this paper are those of the author and do not necessarily represent the views of The World Bank Group.

possible if developing and industrialized countries alike switch to a low-carbon development path. The question of including developing countries in the emission reduction process is not one of ‘if’, but of ‘when’ and ‘how’.

In discussing the issue one should bear in mind that there are still around 3 billion people in the world with an income of less than $2 per day; 1.3 billion of them live on less than $1 a day. Given these statistics, it is hard to argue against the Kyoto approach of limiting carbon abatement in developing countries to win–win measures and those financed by developed countries (e.g., through the Global Environment Facility, or the Clean Development Mechanism). Especially because doing so is consistent with the hump-shaped global emission path mentioned above.

However, the proponents of such an emission path have always made it clear that allowing emissions to rise first does not amount to ‘doing nothing’ (see Wigley *et al.*, 1996. To assure that sharp emission cuts will be feasible in the future, a series of measures are required now. The research and development, policy reform, and technology dissemination paths will be very different from, and more pro-active than, the associated emission path (Austin, 1997). Implementing these preparatory measures in developing countries in a way that is compatible with their development needs is the key issue of the climate change–development nexus.

There are win–win opportunities. Many developing countries are in the process of restructuring their energy sector and are phasing out subsidies. This should yield global environment benefits as well as increasing domestic efficiency. The cheapest way of bringing electricity to rural areas is often through renewable energy systems (e.g., solar PV or wind), which are carbon free. Addressing local air pollution problems sometimes leads to lower greenhouse gas emissions as a spin-off. Realizing these win–win options is crucial, but it constitutes a formidable task. Win–win solutions are often prevented by a complex web of institutional, informational, and market barriers, the identification and removal of which may take considerable effort and time.

Beyond win–win options decision-makers will face a trade-off between domestic development objectives and the need to switch to a low greenhouse gas emissions path in the medium term. Fossil fuels remain the cheapest available energy source to meet the growing demand of developing countries, even when the costs of meeting local pollution standards are factored in. Switching to a more climate-friendly technology would impose additional costs. At the same time, it is desirable for countries to become familiar with climate-friendly alternatives and for the market in these technologies to develop and reach critical mass. Funding from developed countries (e.g., through the Global Environment Facility) therefore remains crucial to bridge the gap between domestic development and global environment objectives.

Climate change impacts and adaptation

Current evidence indicates that developing countries may be more vulnerable to climate change and may suffer significantly more severe impacts than industrialized countries. Vulnerability is expected to decrease over time, as health care and sanitation systems improve and economies become less reliant on climate-sensitive sectors like agriculture. Nevertheless, adaptation to a changing climate is likely to become an increasingly important element of development policy.

Conventional wisdom has it that with significant impacts from climate change not expected for at least another 20 years, adaptation is not a matter of immediate concern. This may be a shortsighted view, for several reasons (the arguments are developed fully in Fankhauser *et al.*, 1998):

- Climate-sensitive investments tend to be designed with respect to weather extremes. There is evidence that weather extremes may change much faster than weather means. It is quite possible therefore that changes in weather extremes, such as crossing certain thresholds, may already be noticeable within a decade or so.
- Many investments (e.g., harbours, roads, dams) have lifespans that extend well into a time when climatic changes can be expected.
- Trends that will most likely make it harder to cope with climate change in the future need to be halted or reversed in time (e.g., development of low-lying coastal areas and river flood plains, fragmentation of natural habitats which affects the ability of species to migrate).
- Certain adaptive measures may take time to develop and phase in.

Many adaptation measures (such as improved coastal zone management) could prove to be worthwhile in their own right. Nevertheless, the challenge of having to adapt to an (uncertain) change in climate should not be underestimated. Available evidence suggests that society's capacity to adapt rationally and proactively is limited. There is a tendency to 'muddle-through'. The El Niño event of 1997/8 (which was probably unrelated to climate change) illustrates this. Despite relatively accurate scientific information about the impacts of El Niño, society's response was by and large reactive, and precautionary measures were rare. The 1997/8 El Niño also showed that even with reasonably good information there is a large potential for surprises.

Adaptation strategies will have to reflect prevailing uncertainties about climate change. The initial focus is likely to be on adjustments in current investment and planning practices, rather than climate change-specific investments. A cautious, but proactive strategy for the short-term might focus on enhancing the general flexibility and resilience of socio-economic and natural systems to react to and cope with climate shocks and extremes, for example by improving safety nets and freeing up markets (thus allowing agents to better react to the signals conveyed by prices). In the case of quasi-irreversible investments with a long lifetime precautionary adjustments may be required already now to accommodate possible changes in climate over the lifetime of the project.

Conclusions

Climate change is a long-term phenomenon, and this constitutes both an opportunity and a challenge. It provides an opportunity because it affords one a certain amount of time to learn, to develop response strategies and to implement them in a way that minimizes costs and does not jeopardize the development prospects of the least well off. To be sure, there is no time to ‘wait and see’. Some policy reforms – such as measures to promote carbon-free energy sources and to increase the adaptability of systems – are called for already now. But there is a certain amount of leeway to prepare an enabling environment before more stringent measures have to be put in place.

The long-term character of climate change is a challenge because current institutional structures provide few incentives to tackle such problems. Institutions are by and large myopic and designed to deal with the short term. Long-term strategies are difficult to implement, especially if short-term costs are high. Moreover, even if long-term plans are agreed on, the government’s commitment to carry them through is often in doubt, and agents will be correspondingly reluctant to initiate the required changes. Climate change is not alone in suffering from these problems, of course. Lack of institutional foresight is also one of the key challenges for the wider agenda of sustainable development.

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The thin pathway for reconciling development and climate change mitigation

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Public choices in global environment affairs are probably too serious to be left solely to economic analysts ; but the writings and sayings of economic advisors shape the opinions of non-economists about policy issues. I have read Bert Bolin’s paper with these two ideas in mind. I had indeed the chance, not only to observe him acting as chairman of the Intergovernmental Panel on Climate Change, but to work directly with him in the little group he convened for the synthesis of the Second Assessment Report (SAR). Though he is a distinguished climatologist by training, he has understood the economic issues behind the negotiation process from Rio to Kyoto and the critical influence of the SAR on the ultimate outcome of this process. Concerned not by climate change as such but by the impacts of climate change and mitigation policies on human welfare, especially in developing countries, he struggled to introduce economists as key contributors and was anxious to learn from them how to harmonize environment and development. Thus economists should read his paper as written by an 'honnête homme' having formed his judgement through discussions with our scientific community. I will comment here upon two sentences that convey his personal conviction about the basic principles which should govern decision-making in this field.

1. 'No extra burden to be financed over and above all other needs in society' : What use of the optimality gap?

Bert Bolin knows that science delivers a 'caveat' but cannot define a form of 'strong sustainability' and provide timely and clear information about the magnitude of impacts of climate change. He is then obsessed with mitigating climate risks without 'an extra burden to be financed over and above all other needs in society': exploitation of 'no regret' GHGs abatement measures, long-run innovation process on non-fossil fuel energies, and attention devoted to the equity concerns. He translates this as the precautionary principle and the intuition that we have both to avoid pre-emption of the long run by the short run and dictatorship by the long run on current generations.

Economists as a profession react sceptically to the concept of 'no-regret'. For them there is no easy way to escape the difficult trade-off between private goods and environment quality and the 'no-regret' may result into a dangerous 'free-lunch illusion'. Admittedly in a world, ridden with poverty, unemployment and uneven distribution of wealth, the 'no additional burden' imperative clearly means that the developing world cannot adopt active climate policies if they jeopardize its conventional priorities. This is why I will try and clarify the linkages between 'no-regret' measures and this imperative.

His paper is symptomatic of a contradiction which has not been solved in the SAR: he recalls the idea of important negative costs technologies as assessed by the Working Group II volume and he quotes the 1–2 per cent of GDP as the macroeconomic costs of stabilizing CO_2 concentration reported by Working Group III. This contradiction has been characterized in the early nineties as opposing the bottom–up analysis based primarily on engineering information and the top–down models which capture economic behaviours in real market structures. But this division is somewhat misleading and has moved since the double-dividend controversy (about the sign and magnitude of side effects of climate policies) became as burning an issue as the efficiency gap controversy.

Economists have not yet fully succeeded in clarifying how crucial should be the design of incentive devices for linking both debates. By the way, the lack of reciprocal understanding between economists and non-economists is aggravated by the fact that the existence of incentive costs has often been viewed as a no-action argument. It is true that the message of economic analysis is that technical change is not 'manna from heaven'; transaction costs associated with any reform of current markets (Jaffe and Stavins, 1994) may narrow negative cost potentials and carbon saving innovation cannot be sustained without timely and long-standing signals (Hourcade, 1993; Schneider and Goulder, 1997). It is also true that the required signals may cause side-effects due to changes in price structures, and in the general equilibrium of the economy, which generate a systematic wedge between gross costs of mitigation policies (sum of costs of abatement techniques) and their net costs. At the end of the story, economic analysis suggests that macroeconomic costs of policies may be lower or higher than total technical costs depending upon the nature of policy signals: if price signals are used rather than technical standards and if the revenue of carbon taxes or auctioned tradable permits is recycled through reducing other taxes, the resulting tax reshuffle is apt to yield a 'weak form' of double dividend which lowers the net mitigation cost. A strong form of double dividend, which would allow for a negative net cost, is achievable only if tax shifting is targeted in such a way that the distortionary effect of carbon taxes or auctioned tradable permits is lower than that of the substituted taxes. Dynamically, this strong form of double dividends prevails if the current spending on R&D is sub-optimal and/or if the allocation of this spending is biased towards carbon intensive techniques.

In other words, in an economic perspective, the path to avoid an 'extra burden' is very thin but exists if current economies are recognized to be located below their production frontier (efficiency gap, fiscal distortions, sub-optimal R&D spending) and if incentive structures are carefully designed to maximize their dynamic efficiency and to minimize the compensation expenditures for the losers. One source of misunderstanding is that, stricto sensu, these measures cannot been labelled 'no-regret'. Indeed the baseline to which climate policies should be compared is not the current or projected state of the world, but the maximum conventional GNP reachable by reducing the optimality gap and without considering climate objectives. If ultimately climate risks are proven rather low, climate policies will be then regretted even if they do not add a burden on current generations: economic growth does not decrease but it does not reach its potential. This is analytically true but, from a policy-making perspective, this ideal baseline remains 'virtual' and discussions would gain in clarity if its contents were made explicit, including the transaction costs of moving towards it.

It would be easier to demonstrate to policy-makers and opinion-makers that costs of climate policies do not simply result from adding up costs of abatement technologies, but depend on judgements about the level of sub-optimality of the economies and the practical ways of reducing it. At this stage the win–win measures depend on an issue linkage exercise: some mitigation measures technically yield an environmental double dividend, but for most of the economic double dividend the policy-maker has to say to what extent the climate objective makes it easier to overcome the transaction costs so far inhibiting Pareto improving decisions (fiscal reform or pricing reform for example).

2. A guide for assessing what alternative development path to choose: beyond the optimality gap

This problem of issue linkage is all the more complex as one passes to the question of innovation and structural change over the long run. The question of structural change is not really serious for those who believe that transition away from fossil fuel based energy supply will suffice to de-carbonize the economy. It becomes critical if one considers: (a) that the substitution between fossil and non-fossil fuels in electricity generation will be made difficult because of the risks associated with nuclear energy; (b) that oil products have important margins of competitiveness, especially for motor fuels, i.e., for the energy use that keeps growing too fast even during the oil shocks period; and (c) that coal has a high competitive advantage in large developing countries such as China and India which it will be politically unacceptable for them to forego.

Consequently, mitigation policy must influence the dynamics of energy demand over the long run and, once it has reduced the efficiency gaps in the whole energy system from primary energy to end use, it must induce structural change: shifts between material-based industries and information-based activities, substitutability between materials, and transportation.

The first difficulty is that energy prices play only a minor role in these matters compared, for example, with the development of just-in-time processes or quality control in the industry, urban planning, the geographical distribution of human settlements and evolution of life styles.

The second difficulty is the bifurcation issue, typically in the transportation sector: aside from lock-in due to learning curves and economies of scale, this sector is driven by a self-reinforcing loop between demand and supply which acts in favour of the system promoted by today's decisions and behaviour. Positive network externalities together with the relationships between transportation infrastructures and geographical distribution of activities, generate a process where market forces tend, beyond a bifurcation point, to reinforce the first choice instead of correcting it, in a self-fulfilling process.

In total, measures in non-energy sectors are likely to have strong consequences for long-run energy paths and we may, in passing, increase the inertia and the carbon intensity of economic systems. If large-scale substitutes to motor fuels from fossil energies prove to be unavailable at reasonable cost in due time, this may have very significant consequences for the long run if one considers the potential explosion of transportation needs in developing countries.

At the same time, coming back to his sentence, it is unlikely we will shift the development path solely because of climate change. But the climate issue can be used as an opportunity for questioning the long-run implications of current behaviours and decision routines. Decisions will flow ultimately from policy judgement about linkages between several types of issues, not from pure economic analysis. But there is an important agenda for economists, to prevent decisions made in passing from narrowing our margins of freedom for the future.

3. Are Kyoto targets on the thin pathway?

Kyoto targets are more ambitious that those suggested by the WRE 550 ppmv path proposed in Nature (Wigley, Richels, and Edmonds, 1996) for a 550 ppm concentration ceiling; they are also tighter than those of Ha Duong, Grubb, and Hourcade (1997) for a stochastic 450 ppm concentration ceiling. None of these simulations discussed the issue of no-regret potentials. Kyoto targets may thus not express a very high willingness to pay for precaution, but it may rather represent what each country of Annex 1 considers roughly as a 'no-regret' objective up to 2012, be it achievable by the true economic baseline, through negative costs measures or measures in synergy with other public objectives.

But despite discrepancies in their results, the common message of WRE and HGH is that, because of inertia in capital stock turnover, a clear distinction has to be made between action and abatement: in case of rigid systems, early action is necessary even if it yields very little abatement over the short term. It then follows logically that ambitious short-term figures are not a good indicator of the relevance of the action: a country which switches from coal to gas in electricity will demonstrate impressive results over the short-term but undertake no action for curbing trends in the transportation sector. The danger is that decisions made in passing augment the inertia and carbon intensity of this sector of the economy, and that price signals emerging from the trading system may come too late to avoid an important burden falling on the flexible sectors of Annex 1 countries.

Finally Kyoto targets will be on the thin pathway of harmonization between environment and development only if developing countries can enter 'Annex 1' after the first budget period (2012). The two burning questions of the 'no extra burden' and of the selection of development paths are to be addressed in a rather short period of time; developing countries are indeed under pressure of various forms of urgency and are not in a position to select their development pattern. The Clean Development Mechanism decided at Kyoto should be designed to provide an incentive structure for helping countries building up huge infrastructures, not to embark blindly on a carbon intensive development path.

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Implications of global climate change and the economics of development in Sub Sahara Africa

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1. Overview

Bert Bolin identifies three key factors affecting global mean surface temperature: increased atmospheric greenhouse gas concentrations (carbon dioxide, methane, nitrous oxide, halo carbons, tropospheric ozone); enhanced concentration of sulphate aerosols resulting from combustion of fossil fuels; and smoke from biomass burning.

Global mean surface temperature is said to have increased by about 0.5°C during the twentieth century. Atmospheric greenhouse gas concentrations which have a long lifespan in the atmosphere (about ten to 150 years) continue to increase. Biomass burning in Sub Sahara African (SSA) countries may contribute both to GHGs and to short-term weather change through emission of smoke. Smoke may contribute to atmospheric cooling. However, its lifespan in the atmosphere is just a few weeks. Despite the uncertainty surrounding the extent and sensitivity of climatic system to greenhouse gas forcing on the climate, due to counteracting forces between the cooling effect of fossil fuels and biomass burning–against greenhouse gases accumulation, a discernible human influence on the climate has been established.

The major effects on SSA include; raising of sea levels, floods, freak weather conditions, and water shortages.

Changing rainfall regimes, may create havoc in these countries such as experienced currently with the 'El Niño' phenomenon. Floods have devastating effects on the infrastructural services of the country, especially communications. The recent experience in Kenya and Tanzania has shown that roads and railways are most vulnerable to destruction by floods. The spillover effects of such destruction is to paralyse the transport network causing difficulties in moving both passengers and goods. The impact of this is, first, to retard economic performance due to shortages of production inputs and consumer items and second, to require significant resources for road and railway repair.

Increased rainfall may benefit populations with water shortages for domestic use and production. But if water catchment areas have been destroyed due to deforestation and abuse, the opposite may be true. (Moreover, since trees act as sinks for carbon dioxide, global warming will tend to increase unabated.)

If rainfall becomes unpredictable and unreliable as well, farmers will experience increasing uncertainty. Unpredictable rainfall in terms of quantity and timing throws farmers off balance and affects yields. Possible results include famine and current account trade deficits. Less will be exported, more will be imported. If food is not given as aid, countries have to borrow in order to import food. This will also affect foreign debt.

For SSA countries bordering the seas and Island nations such as Zanzibar, Seychelles, Madagascar and the Comoro among others, a rise in the sea level may spell disaster. Land for dwelling and production will be lost. People will be relocated and forced to be refugees elsewhere. Production and income generation opportunities will be forgone.

2. Mitigation challenges

The paper notes that mitigation of adverse climate change due to human activity may be achieved through the control and adaptation of those activities, and through the introduction of better practices, i.e., environmentally friendly practices, made possible through technological improvements and development. Costs and benefits are crucial in motivating mitigation efforts. Only when the costs of climate change exceed the benefits will people have an incentive to correct the imbalances.

Two levels of costs and benefits incidence are identified: local and global. Individual countries are bound to measure the local costs and benefits first before embarking on the measurement of benefits and costs at the global perspective. For the SSA countries, their net contribution to the global climatic change is that of warming rather than cooling. However, the magnitude of this contribution is much less than that of industrialized countries. This is both because of the sink factor helping to neutralize the accumulation of CO_2 in the atmosphere, and because of differences in per capita emissions.

The ongoing process of deforestation (due to most of these countries falling back on age-old natural resources for survival in this liberalized and increasingly globalized trade) means that the sink factor will continue to be diminished. To maintain or even improve this function of carbon sink, SSA countries citizens need both to invest their time and financial resources, and to forego some current consumption habits and patterns. Some of those consumption habits impinging on the sink function are: consumption of woodfuel and construction timber and clearing for agricultural expansion or shifting cultivation due to lack of fertilizer inputs. The investment required to improve the function involves afforestation programmes which need financial resources for mass education, the supply of seedlings, extension services, and related inputs.

Consider the technological alternatives. To change consumption habits, it is necessary to have effective energy alternatives or substitutes for woodfuel. Solar power for direct heating and cooking is still yet to be popularized. Two major stumbling blocks prevent the spread of use of this new and renewable energy. The first constraint is cost. Given the low incomes of most rural dwellers in SSA, the technology is not affordable. Those who can afford it tend to have other options such as electricity or gas. Secondly, the utilization culture which comes with the solar heaters for cooking necessitates changing habits. Solar cookers have to be used outside when the sun is hot. In most parts of SSA, the sun is plentiful throughout the year. However, cooking habits by the solar cooker technology may take time to be adopted even if the ability to acquire these facilities is attained much earlier. This therefore makes the solar cooker an unattractive option in these countries.

Another option is Biogas. This alternative however is confined to cattle keeping areas, and areas where adequate and appropriate farm residues, e.g., sisal processing residues exist. Popularization of biogas is slow and caters mainly for heating (cooking, boiling, etc). Gas can also be used for lighting. However, this is not the most popular way of gas utilization. Again, high costs for construction of the biogas digesters, are partly responsible for the slow adoption rates. Electricity is definitely one of the most effective energy substitutes especially for agro-based industries such as tobacco curing and tea processing. These industries are, however, normally located in the rural areas away from the national power grids. It is expensive to connect them. Furthermore, electricity prices relative to other energy sources do not encourage switching (Kulindwa and Shechambo, 1995).

Similar considerations determine the choice of farming technique. Deforestation due to agricultural expansion is often brought about by the poverty of smallholder farmers combined with the high costs and poor availability of fertilizers (Bagachwa *et al.*, 1995). Extensification of farming results from a strategy of using virgin land rather than fertilizers. In Zambia, over 90 per cent of deforestation is the result of land clearing for agriculture, while in Tanzania it accounts for about 40 per cent (Reed, 1996).

So, the quest for maintaining carbon sinks for the absorption of the carbon dioxide in the atmosphere entails some difficulty trade-offs for SSA. Unless farmers (who are the majority) get alternative ways of earning their subsistence or change their farming practices it will be difficult to stop or even reduce the rate at which our forests are disappearing.

A compromise way of dealing with the contribution to climate change in SSA, includes mitigation adaptation and improvement of knowledge. The appropriate portfolio will differ from country to country. But it is important to recognize that, the ‘environment’ as such is *not* ‘priority number one for developing countries’ (even for most industrialized countries). For SSA countries, mitigation of environmental damage which lead to global climate change, requires the use of resources that are in high demand for poverty alleviation and provision of basic needs. As long as these societies remain at a low level of development and in poverty, the mitigation of environmental damage by reallocation of the meagre resources they have, or by changing their production practices and consumption habits in the face of limited alternatives, may prove to be *utopian*.

Globalization of the world economy puts the least-developed economies at a disadvantage due to their weak bargaining position in the world market. They do not have a say or an edge in most fields in the compassion for global resources. Due to the nature of the structure and trade conditions in the world market, many environmentally unfriendly production practices which lead to deforestation occur as a response to market signals at the global market level (Kulindwa and Mjema, 1994). Tariff structures have been found to encourage the export of unprocessed extractive primary and agricultural products which are produced in a way that harm the environment. The export of unprocessed or even low-level processed exports, reduce their value added content and hence result in the net transfer of resources from developing to developed industrialized countries. The resources needed to enhance sustainable development of these countries are concentrated in the hands of those who have the competitive advantage technologically and global market power.

3. Conclusion

Since environmental degradation (the likes of that discussed above) causes climate change it has trans-boundary nature global effects. A purposeful strategy has to be established for the successful achievement of the objective of maintaining and creating GHG sinks. This should involve sharing technological information and hardware for environmentally sustainable behaviour, e.g. energy efficient technologies, and practical and effective farming methods.

Realistically, SSA countries' position should be looked upon within a 'partnership' rather than an 'independent competitive' approach. In order to succeed in mitigation it should be understood that the gravity of the daily survival/subsistence struggle takes priority over anything else. The argument normally extended is that, one has to be there first in order to conserve or enjoy the fruits of a conserved environment. If one fails to provide the basic necessities to enable oneself to be there tomorrow, the prioritization of environmental conservation for its own sake becomes absurd. Therefore, due to the high incidence and levels of poverty in most SSA countries, programmes and policies on climatic change should go hand in hand with programmes and policies for poverty reduction and ultimately eradication, because poverty has been identified as both a cause and an outcome of environmental degradation.

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Global climate change: science and sustainable policies

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Professor Bolin's paper is comprehensive in its coverage and deeply perceptive in its analysis. There is really very little that one can add to the subjects covered by him by way of additional commentary or elaboration. At best one can refer to some issues covered by him and highlight them for emphasis. The science of climate change has, of course, been put across lucidly in Professor Bolin's article. The one scientific issue that I think deserves discussion is that related to the level at which stabilization of carbon dioxide must be achieved, and which would really be the guiding force for mitigation and adaptation initiatives. Professor Bolin refers to the agreement of the European Union that global mean temperature should not exceed about 2°C, which in turn means that stabilization of carbon dioxide must be achieved at a level not exceeding 60–80 per cent of the pre-industrial level, i.e., between 450 and 500 ppmv. The conventional wisdom today and the focus of climate change negotiations seems to be 550 ppmv. This really means that the mean temperature increase globally may exceed 2°C and consequently the impacts could be disproportionately higher, consequent to this increase. It is not for no reason that the small island states are, therefore, deeply worried about their future, because sea level rise in several of these states could literally wipe out opportunities for their future livelihood and physical security, through inundation of areas of land on which human habitation has existed for centuries.

It would be pertinent for us to remind ourselves of the concerns that President Gayoom of the Maldives voiced at the 13th Session of the IPCC held in that country in September 1997. He said on the occasion 'Ten years ago, in April 1987, this very spot where we are gathered now, was under two feet of water, as unusually high waves inundated one-third of Male', as well as the Male' International Airport and several other islands of our archipelago.' Exceeding the 2°C limit set by the European Commission would only enhance the risks to communities living on such islands, and clearly the global community has not only to be sensitive to this possibility, but also assume responsibility for mitigation of this disaster which appears increasingly probable. Professor Bolin rightly says that the uncertainty of the scientific findings so far imply that the issue of a future change of climate should be considered as an issue of risk. Those who think within limited time horizons and who apply high discount rates to future actions and outcomes, would undoubtedly minimize their assessment of future risk. But, on the other hand, those whose preference functions include inter-generational equity values and who discount the future at very low rates, would obviously see the magnitude of risk from climate change very differently. There is obviously a cultural issue involved in these assessments. It would perhaps be no exaggeration to state that those cultures that have a tradition of extended families and different generations living together or where the community spirit is strong, would have somewhat different assessment of future risks to be faced by their children and grandchildren than would cultures that essentially live in nuclear families. There is inherent in this situation the possibility of a conflict in objectives, perception and values. Nevertheless, even if inter-personal preference functions do not explicitly include the welfare of future generations in a particular family, then at the aggregate, for humanity as a whole, it would not be misplaced to assume that civil society of today at the global level accepts some ethical and social responsibilities for the next generation, irrespective of where they are and who they would be. After all, even today a diverse and broad-based organization such as the United Nations is still able to provide disaster relief and assistance to communities far away and in corners of the globe that several decision makers in the UN system are perhaps not even familiar with. The issue of risk from climate change globally, therefore, has to be seen within the context of global responsibilities.

Interestingly, the market has perhaps been far more sensitive to the threat of climate change than various bodies that represent current forms of global governance. For instance, the insurance industry, as Professor Bolin points out, has noted damages in recent decades due to extreme weather events, with major losses having been experienced in the Caribbean region and in the Pacific. As scientific evidence becomes available and information dissemination on climate change more widespread, insurance costs are likely to increase sharply. In those areas that appear most vulnerable to the impacts of climate change, Professor Bolin rightly says 'to use statistics of what has happened in the past is no longer a viable approach'. The insurance industry, whose entire approach in decision making and in its operations is based on assessing the future, is likely to be ahead of other sectors of the economy in this aspect. In their case, statistics from the past would only be a basis for predicting the future, which in turn will be driven largely by scientific knowledge.

Another important point made by Professor Bolin which is at the heart of the climate change debate today relates to the IPCC view that 'a prudent way to deal with climate change is through a portfolio of actions aimed at mitigation, adaptation, and improvement of knowledge'. However, the weights that would be attached to each one of these three areas of action would vary across countries, making the task of consensus building complex and contentious. Indeed this came out clearly in the preparations leading up to Kyoto and what actually happened in Kyoto.

As far as mitigation action is concerned, Professor Bolin separates these in terms of technical potential, economic potential, and market potential. However, such a neat separation is seldom possible. For instance, any action to improve energy efficiency cannot be seen purely in terms of its technical potential without looking at the economic or market potential. Theoretically, for instance, the technical potential for energy efficiency could be merely stoppage of any activity that results in emissions of GHGs, but the economic and market costs of this would be enormous. The technical potential, therefore, has to be related intimately with the economic potential. Understandably, there could be a gap between the economic potential and market potential, which arises out of market failure, simply because prices in the market do not necessarily reflect economic costs and benefits of specific mitigation measures. This is a huge area for research and provision of inputs into the policy process. Of course, such market failure is not unique to global environmental problems, because it is widespread and ubiquitous in the area of local environmental damages. However, it is far more complex in the case of global environmental damage, because we are dealing with nation states, undefined rights to global environmental space, and varying contributions to the concentrations of GHGs in the atmosphere, which are the result of cumulative emissions historically produced by different communities and countries. Theoretically, at least, therefore, it should be possible to assign a price for cumulative emissions to those societies who have been responsible for such emissions in the past, and who should, therefore, pay for them if they are to continue to emit GHGs now and in the future. Since the current regime does not assign such costs, there may be some logic in the view that the developing countries are actually subsidizing the growth and economic well being of the developed countries, since they have already occupied far more than their due in environmental space.

One issue that does not get appropriate place in Professor Bolin's article is the whole issue of technology development and scientific endeavour which might result in technologies that could mitigate climate change in the future. He has discussed several options in specific sectors of the economy and has highlighted the need for changes in the future such as the need for reducing motorized transport and shifting demand to less energy intensive transport modes as part of an important long-term strategy. However, it is unlikely that, given the difference between social costs and benefits and those assigned by the market, intervention by governments to bring such benefits into existence would be essential and inescapable. What form or approach these government interventions should take is a matter that requires intensive debate. A case is not being made that governments themselves must undertake research and development for evolution of new transport systems in practice, but that we would need to develop incentives and disincentives by which the private sector itself could develop these technologies in response to perceived market compulsions that are triggered off as a result. But, of course, governments would take such policy measures only if they wished to pursue an emissions trajectory that would involve substantial reductions in the future. This is where Kyoto has been, in some sense, a failure, because it has hardly reached any targets for the period specified, i.e., 2008–12, which might lead to aggressive action by national governments in the directions mentioned above. Nor has there been any effort to define a long-term trajectory that might induce appropriate R&D initiatives today. Technology is clearly seen as a major component of any mitigation strategy in the future, but there is a notable lack of a technology development strategy in discussion and debates on the subject. It would be useful for some conceptual and thematic contribution from Professor Bolin in defining a technology strategy for the future. Undoubtedly, there is no such thing as a global technology strategy that deserves elaboration, but there may be institutional innovations and policies that have universal relevance. This is an issue which needs considerable attention between now and Buenos Aires and beyond.

Free ride through delay: risk and accountability for climate change

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Bert Bolin's paper admirably summarizes the second assessment report of the Intergovernmental Panel on Climate Change (IPCC). So this could be a starting point to see what the concerns of developing countries are. They wish to be active and decisive partners in the collective decision-making process and wish to ask:

- What concentration levels along with the associated risks are acceptable to the developing countries?
- How could it be ensured that the risks to the developing countries, and not just the costs to the developed countries, are minimized?
- If Annex-I countries prolong their commitments to reduce the emissions, they use up limited carbon emission budgets available for future. How will it be available to the developing countries when they need it for their growth?

The assumptions about greenhouse gas (GHG) concentration levels for stabilization range from 450, 550 and even 1000 ppmv! (for example,

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We thank K.S. Kavi Kumar for carefully reading and making useful comments on various drafts of this note.

Wigley *et. al.*, 1996).[1] Each of these permit different reduction strategies. Freedom to choose options is limited to the case of 450 ppmv as the carbon budgets are very low and therefore immediate actions are needed. Currently integrated assessment models are being developed to resolve these issues. Unfortunately, assumptions, premises, and paradigms dictate the results of these models, and they need to be discussed. Often, the developed countries' perspectives are hardwired into the models in such a manner that even if many scenarios are generated, the basic theme and results do not change. These models focus on minimizing costs to the developed countries and not the risks to the developing countries. The decision about what is the acceptable level of climate change should centre around the risks to the developing countries. In fact, the developing countries should have a greater say as they are more vulnerable to the impact of climate change; they have a very small share in the cumulated emissions; they are poor and their emission trajectories are likely to rise due to development. Nowhere are large polluters given opportunities to decide what cost and efforts are acceptable to them. The level of efforts needed is decided on the basis of what is good for the society. What are the risks associated with these levels of emissions and the associated climate change?

Risks associated with climate change

The FCCC objective states that the GHG concentrations should be stabilized at levels where food production is not threatened (FCCC, 1992). Thus by examining the impact on agriculture of different climate change scenarios, one can get an idea of what is tolerable. Rosenzweig and Parry (1994) have estimated significant adverse impact on the agriculture of many developing countries. In a more detailed study of India, Kumar and Parikh (1997 and 1998), examined the impact on agricultural yields, output, income, and prices. They estimated that: (a) yield losses (without considering the carbon fertilization effect) for rice vary between 15 and 42 per cent and for wheat between 25 and 55 per cent for temperature increases of 2.5°C to 4.9°C; GDP would drop by between 1.8 to 3.4 per cent and agricultural relative to non-agricultural prices would increase by 7 to 18 per cent; (b) even with carbon fertilization effects, losses would be in the same direction but somewhat smaller; (c) with adaptation by farmers of cropping patterns and inputs, losses would remain significant; with a temperature change of +2°C and an accompanying precipitation change of +7 per cent, farm level total net revenue would fall by 9 per cent, whereas with a temperature increase of +3.5°C and precipitation change of +15 per cent, the fall in farm level total net revenue would be nearly 25 per cent. For developing countries, these are very large changes which can cause much human misery. From India's point of view, a 2°C increase would be clearly intolerable. Other developing countries may be even more vulnerable.

Increased occurrence of extreme events due to climate change will also

[1] It should be noted that as per the IPCC assessment a doubling of CO2 concentrations can lead to an equilibrium warming between 1.0°C to 3.5°C (IPCC, 1996)

affect the poor most. In the cyclone in Andhra Pradesh in India in 1996, more than 1,000 people died and there was huge property loss. Cyclones of similar intensity in advanced countries like the US, may not lead to any deaths, if at all.

Large-scale out-migration from coastal zones is expected due to sea level rise. Furthermore, intrusion of sea water in the ground water and changes in temperature can reduce agricultural incomes. This will create a large number of environmental refugees especially from low-lying delta regions in poor countries. Countries dependent on agricultural production, which most often include developing countries, are likely to be adversely affected.

In the climate change debate there is increasing reference to the need for adaptation to climate change. Adaptation ranges from switching to different crops to migrating or giving up land rights if they are in the coastal areas. Rosenzweig and Parry (1994) have indicated increased hunger in developing countries which is also one way the poor adapt. In any case, adaptation will be too all-pervasive and costs too difficult to isolate for compensation. The estimates for costs to build walls along the vulnerable zones to sea level rise for the USA is $107 billion in 1989 prices (Yohe, 1990). That may be a small share of the GDP of the USA, but such measures, even scaling for their coast lines, for say, Bangladesh, could require very large share of their GDP. Who shall pay Bangladesh for such a wall?

These risks to poor countries should be the primary focus of the climate change analysis, rather than costs to the developed countries. To this extent, a paradigm shift is necessary from cost-minimization to risk-minimization in the future analyses of IPCC.

Delay is free riding, actions are needed now

Unfortunately, at the recently concluded Conference of Parties (COP) in Kyoto, Annex-I countries again delayed their commitments,[2] and what little they agreed has still to be ratified in their home countries. Annex I countries need to take urgent actions for consensus building exercise for their local decision-makers.

The uncertainty as to the extent of climate change is used by different countries to argue when and what actions need be taken. A vulnerable country like India would focus on the higher end of the warming range and urge action now. On the other hand, a country with more resources and a robust economy like the USA seems to focus on the lower end of the range and wants to delay action. If, however, the risks turn out to be as India fears, will there be compensation from the USA for the delay? One should note here the inequity. The distribution of per capita carbon emissions between regions is highly skewed. The USA has a per capita emission which is approximately 20 times that of India.[3]

[2] On the whole the Annex-I countries are expected to reduce their emission by 5.2% in the next fifteen years over their 1990 levels. Of this, the USA is expected to reduce by 7%, the EU by 8% and Japan by 6%.

[3] Within the North, USA's per capita emission is 5.03 ton per year which is twice as much as that of many countries in western Europe. The same is true in the South too; Brazil has a higher per capita emission (0.38 tons per year) than the rest of the South.

Delay is a way of free riding. To discourage free riding during the negotiation period and beyond, we suggest that countries are accountable for their own emissions for a specific period, say after 1990 or 1998. That is, the clock starts ticking and all emissions are cumulated for each country even during negotiations. This way negotiations will conclude faster and policy actions to reduce emissions will begin sooner. Regardless of the outcome of the negotiations, these emissions will be shown against each country and that much less will be available to them in future. This way, the countries taking actions in advance get their rewards and procrastinating countries will have to do more later. The only fair allocation of the global environmental space is on a per capita basis. The desirability of distributing permits (quotas) on a per capita basis is recognized at least in the long run (Manne and Richels, 1993). The belief that 'all men are created equal' was voiced eloquently in the US Declaration of Independance and was a message 'heard around the world'. If the population is fixed in the year in which the agreement is reached, the South does not profit from population growth.

One way out of the differing perception of risk could be as follows. As a number of uncertainties surround the predictions about future temperature rise following climate change, the GHG concentration leading to a temperature rise of 1.5°C could range from 450 to 700 PPMV.[4] The corresponding range of total cumulative emission is 640 GTC to 1330 GTC. And, of course, one can define the trajectories of emissions over time that correspond to the two endpoints of the range. We can take these extreme trajectories and allocate emission rights on a per capita basis to different countries as per each of the trajectories. As and when our knowledge improves and uncertainty is reduced, we can narrow this range and revise the allocations. Those countries who have emitted more than their share in a cumulative way must offset this by larger reductions. Also the responsibility to compensate fully those who have suffered damage should also be based on this cumulative additions to atmospheric CO_2. Each country can be left free to select which emission trajectory within the range it wants to follow as long as it accepts responsibility to fully compensate others for its emissions in excess of its quota as per the minimum trajectory, and no country is permitted to emit more than its share as per the maximum trajectory. Thus, for example, the US may follow the emission trajectory that corresponds to a 700 ppmv equilibrium concentration, but if scientific knowledge narrows the range and establishes 550 ppmv, say, as the desirable concentration, then the US would have to vacate all cummulated emmissions it made in excess of its new quota trajectory as per the 550 ppmv equilibrium concentration, and of course it must be liable for the damage caused by its excess emissions. This is just an extension to the global commons of the polluter pays principle accepted by most countries domestically. There is no logical reason why it should not be followed internationally. Similarly liability laws in most countries require those who have caused damage to fully compensate the victims. Such a system would

[4] Note that different assumptions about climate sensitivities could lead to such wide range of possible GHG concentration.

reduce the temptation to use delaying tactics to free ride on others. The options for policy actions could be further enlarged if we also institute a system of leasable emission quotas. As is well known, such a system will: attain a given atmospheric level at least cost, induce developing countries to select a carbon efficient path, create incentives to develop and adopt new technologies, provide a natural way to price new technology in the market, and encourage joint implementation in a fair way.

Concluding comments

Disappointing delay at Kyoto leads us to suggest a system where all countries should be accountable for their cumulated emissions, say after 1990 (or 1998). When final negotiations are concluded, those countries which have taken early action will be rewarded and the others will have to do a lot more later.

- Despite the uncertainties surrounding climate change, the risks of potentially adverse impacts on the food system, coastal zones, and increased occurrence of extreme events should be avoided by early action.
- Even during the negotiation period, an immediate decision to cumulate emissions for each country from a given year, say 1990 or 1998, will reward early actions and perhaps conclude negotiations faster.
- To give countries some leeway to deal with the uncertainties involved and their differing perspectives of risk, countries must be held accountable for the damages caused due to their cumulative emissions over the most pessimistic scenario (i.e., one which restricts atmospheric CO_2 level to the lower value) but may be permitted to emit up to their quotas as per the most optimistic scenario. For greater flexibility quotas should be leasable. There are many desirable consequences of such a system. It will optimize response and reduce free riding through delay. As we have observed the cost of delay in emission reduction (by the North) in terms of the South's foregone opportunities to development is substantial. This will impose many constraints on the way the South decides on policy options regarding issues such as how to generate power, how to use land, and what crops to grow, and so on. Moreover, the South is highly vulnerable to the impact of climate change. Hence, unless the North acts now, North–South transfers of large amounts will be needed to compensate the South for the development opportunities foregone.
- The risks to poor countries should be the primary focus of the climate change analysis, rather than costs to the developed countries. To this extent, a paradigm shift is necessary from cost-minimization to risk-minimization in the future analyses of IPCC.

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Economic development and climate change

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Doing cost–beneift analysis

Bert Bolin's paper offers us a helpful rapid *tour* of the state of climate science (Bolin, 1998). There has been warming, and it looks as if it is due to human intervention. If this is correct, then there will be more warming, and it is as well to remember that the process does not stop in 2050 or 2100 simply because we choose those years as 'benchmarks'. But there are considerable uncertainties. For some, uncertainty means we should do more research but little or nothing by way of policy because the payoffs could be negative. For others, uncertainty is used to justify drastic action now, usually with reference to vague criteria such as the 'precautionary principle'. Given these diverse reactions to uncertainty, one would expect to couch the policy problem in terms of costs and benefits, yet Bolin is of the view that 'traditional cost–benefit analyses are hardly possible at this stage because of the need to assess future damages reasonably well'. I do not agree. Of course, if the existing science is uncertain, then the cost–benefit analysis based on that science is also uncertain. If we are additionally uncertain about the nature of the impacts, the uncertainty is increased. If we are then uncertain about the economic values to be attached to the impacts, we have still greater uncertainty. But it is better to have a cost–benefit assessment embodying these uncertainties than to make no attempt to do one.

There are some compelling reasons for doing 'global' cost–benefit analysis. The first is that each stakeholder in the process will do their self-interested cost–benefit analysis anyway. Indeed, we know this is true because that is precisely what happened in Kyoto in December 1997. Countries as diverse as Australia, Japan, Iceland, and Norway pleaded that they were 'special cases', whilst the USA was bargaining from a position of known public and Congressional hostility to cuts back home. All thought they should not have to bear the burden of significant emissions reductions. These countries revealed a low coefficient of concern for the rest of the world but a strong certainty that, for them, costs exceed benefits. In the absence of any global cost–benefit assessment there is no valid way to say whether their apparent selfishness is at odds with a global view. We cannot measure the divergence between their apparent coefficient of concern and the one needed to produce action on climate change.

Second, a global cost–benefit assessment should give some idea, however crude, of who gains and who loses. Engaging in 'impact analysis' does this successfully only at the extremes: some small low-lying islands face high negative pay-offs, but who is to say whether the net effect on, say, Russia or the USA is positive or negative in the absence of some aggregated measures of gain and loss?

One of the tragedies of the IPCC process was its failure actually to do cost–benefit analysis. This perhaps derives from the at times obsessional concern of IPCC not to make policy judgements, a mistaken carry over from the idea that science is, or should be, 'value free'. Actually comparing costs and benefits would presumably imply recommending little action if costs exceed benefits, or recommending more dramatic action if benefits exceed costs. IPCC cannot be seen to do that. One result is a lack of guidance to policy-makers on just what the costs and benefits are, leaving them to engage in their own self-interested evaluations.

Yet there is information in the 1996 IPCC Reports that permits some evaluation of costs and benefits. The *damages* from global warming are very clearly set out in Pearce *et al.* (1996). The *benefits* of control are not the same as the avoided damages because the control policies involve reducing greenhouse gases that are jointly produced with other pollutants and sources of environmental nuisance. Thus, traffic restraint reduces carbon dioxide, but also damaging local pollutants such as particulate matter, local nuisances such as noise and disruption, and transboundary pollutants such as nitrogen oxides and volatile organic compounds. The best way to characterize these benefits is in 'marginal' terms, i.e. as the extra benefit obtained from reducing greenhouse gas emissions by one tonne. Pearce *et al.* (1996) reported those estimates. In 1997 dollars, they would now appear to be around $25 tC for the 'primary' benefits, and perhaps that sum again for 'secondary' or 'ancillary' benefits. We can be fairly safe in saying that the marginal benefits of control are at least $50 tC.

Finding a comparable marginal control cost, i.e., the extra cost of reducing emissions by 1tC, is more difficult, despite the plethora of studies on control costs. But it is difficult to believe that it is greater than $20 tC for the context in which the benefits estimates are applicable. Some would argue that it is considerably less, and others might point to the likely prices at which tradeable permit schemes might settle. Figures here seem to be of the order of $2 to $5.

Marginal benefits therefore appear to exceed marginal costs of control by a significant margin, so much so that even if global warming turns out to be 'untrue', the secondary benefits of control could justify fairly aggressive action on climate change (Pearce, 1996).

The developing countries' interest in action on climate change

One other result of the global cost–benefit studies is that they fairly clearly indicate the higher relative burden borne by the developing world. The studies reported in Pearce *et al.* (1996) suggest that global damages for '2× CO_2' (i.e. for the point at which atmospheric concentrations are doubled relative to pre-industrial levels) would be 1.3–1.6 per cent of GDP for the OECD bloc of countries, but 1.6–2.7 per cent for non-OECD countries. This suggest that developing countries should, out of sheer self-interest, seek to encourage aggressive action on climate change. Some have done so, but again only for the 'extremes', e.g., the small island states who fear they will lose very large proportions of GDP and economic assets. The self- interest of the G77 bloc cannot be served, however, by arguing that they are simultaneously the worst affected but also the least in need of taking action. If the levels of control required to reduce the developing country impacts were left to the developed world alone, the cutbacks would be such that developing countries would lose more simply from trade related effects, i.e., from the reduced demand for their output. That becomes even more true once one recognizes the rate at which greenhouse gas emissions are growing in the developing world relative to the developed world. The developing country negotiating stance of underlining the 'differentiated responsibility' of the developed world for climate change is thus shown by the monetary damage estimates to be untenable. If they do not accept targets and take action to reduce emissions, they effectively place their own futures at risk either by shifting burdens to the developed world which will reverberate on them through trade, or by making developed country burdens so great they will not happen anyway because of domestic resistance, thus damaging the developing world through climate change.

While the United States did not equip itself well at Kyoto, it did at least strike the right note in insisting that any Protocol should include the developing world. That may not have been popular among the unworldly moralists who haunt the climate change stage, but it was realistic.

Science and the future climate

The scientists involved in climate change research have served us nobly, and none more so than Bert Bolin whose dogged insistence on the highest standards has survived in a context where others have sought to insult science for their own ends, as we saw with the IPCC Working Group III proceedings, or, to engage in slurs on the motives of scientists (e.g., Beckerman, 1997). But as long as science avoids the confrontation with the uncertainty that is endemic to climate change, it offers policy-makers with little that they can use to persuade others. The context of uncertainty cries out for an appraisal of costs and benefits, however crude.

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Burden-sharing and climate change policy beyond Kyoto: implications for developing countries

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1. Introduction

Bert Bolin has written an excellent summary of the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report and provided valuable insight to its broader implications. My comments will be confined mainly to three of the policy-related points in his paper:

1. Because impacts cannot yet be estimated very well, traditional cost–benefit analyses are hardly possible at this stage because of the need to assess future damages reasonably well.
2. *Cost estimates are, however, important for the choice of strategies and to reach agreements on how to share the burdens within countries, between countries and between generations* (author's emphasis).
3. Social and political values, not the least concerning equity, come into play as has so clearly been seen in the past. This will certainly also be the case in the future.

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My emphasis will be on the issue of *international equity* (fairness) and its implications for burden sharing. This will be discussed in the context of emissions trading, provision for which is prominent in the recent Kyoto Protocol (FCCC, 1997). Emissions trading, such as marketable permits/entitlements or tradable quotas, has the attractive feature of simultaneously being able to promote both efficient and equitable outcomes. This policy instrument can be modified in several ways to gain greater future involvement by developing countries in a truly global climate accord.

2. Background

Since no supranational authority exists that can impose a climate agreement, it is highly dependent on voluntary action. A global problem requires a global solution and hence the participation of all nations. Although historically most of the greenhouse gas (GHG) emissions in the atmosphere have been emitted from industrialized countries, future progress in limiting significant increases in GHG concentrations requires the involvement of developing countries. Several policy proposals have been put forth, many of them with an emphasis on efficiency, or at least on cost effectiveness. Even with overall costs kept to a minimum, however, involvement by developing countries will only be feasible with the identification of near costless options or with financial assistance from industrialized countries. The extent of the latter will depend on attitudes toward international equity and balancing of alternative concepts through the negotiation process.[1]

Several studies have laid out the details of permit markets for global warming (see, e.g., Barrett *et al*., 1992; Tietenberg and Victor, 1994). This policy instrument is more likely to lead to cost-effective outcomes than alternative approaches, most notably inflexible emission quotas. Equity can be addressed head-on by the manner in which permits are initially distributed. Moreover, this instrument has one advantage over most others, in that it overcomes efficiency–equity tradeoffs, which are often a justification for relegating equity considerations to second priority or dismissing them altogether. These tradeoffs arise when the pursuit of equity undercuts efficiency through disincentives (as when transfers are unrelated to effort). The disincentive effect is muted in this case by giving all parties to the agreement a stake in the environment.

It should not be neglected, however, that a permit market represents an international exchange process, and that developing countries are

[1] Although most economists are agreed upon the best definition of economic efficiency, there are numerous competing definitions of equity. Several alternatives include: vertical equity (reducing disparities between rich and poor), horizontal equity (treating all nations equally), Rawls maximin (favoring the least well-off nations), egalitarianism (treating all people equally regardless of location), and market justice (considering the exchange process itself to be able to lead to a fair outcome). The reader is referred to Rose (1992), Rose *et al*. (1998), and Bohm and Larsen (1994) for more in-depth discussions of alternative criteria and their implications for relative welfare changes among countries participating in an international agreement.

often concerned about actual and perceived instances of 'unequal exchange', in which industrialized countries are seen to have the upper hand (see, e.g., Agarwal and Narain, 1991). This concern, however, can be overcome by properly designing an international GHG emission permit market.

3. Kyoto and burden-sharing

Equity issues arose at the Third Conference of the Parties to the Framework Convention on Climate Change (COP-3), held in Kyoto in December 1997. First, nations of the world were bifurcated into two distinct groups: industrialized and developing countries. The former had previously committed to targets and timetables for GHG emission reductions, while the latter resisted these commitments.[2] The fact that industrialized countries were willing to move ahead with their own commitments, while placing only a modicum of pressure on developing countries to join in, can be perceived as an appreciation of historical responsibility for current GHG concentrations and for income disparities. Obviously, issues of pragmatism entered into this stance as well.

A related consideration is *differentiation*: 'Some Annex I parties or groups of parties would have commitments that are different from those of other Annex I parties or groups of parties' (FCCC, 1996). There have been many attempts to portray differentiation rules as neutral, objective, or devoid of equity aspects. Another view is that they are entirely based on self-interest. In essence, they are appeals to special circumstances in various countries (e.g., Australia's dependence on coal both for domestic use and export, Norway's dependence on oil and gas exports, and adverse conditions in several transitional economies). Elsewhere, it has been shown that the various differentiation rules are hardly neutral and are in fact equivalent or nearly equivalent to specific equity principles (Rose *et al.*, 1998). Thus, individual country exceptions from the overall target of a 7 per cent reduction of GHGs below 1990 levels (see table 1) had to be accepted by their Annex I counterparts, at least in part, on a fairness basis.[3]

Overall, however, the Kyoto Protocol finessed the ultimate issues with respect to developing countries. The current exemption for this group cannot be sustained if GHG concentrations are to be stabilized. Two major insights can, however, be gleaned from the Kyoto outcome. First, industrialized countries do have some sensitivity to fairness, as well as to political considerations. Second, there is an involvement potential for developing

[2] The industrialized countries signing the accord are referred to as 'Annex I' countries, relating to their listing in an appendix of the COP-2 agreement, which was held in Berlin in 1994 (hence the designation 'Berlin Mandate').

[3] I suspect that differentiation is intended to have a neutral connotation in part because equity becomes a two-edged sword for industrialized countries because the relative gains from this use of this concept on the up-side are likely to be small in comparison to the weakening of position with respect to the many more numerous developing countries on the down-side (per capita income differences between Australia and the US are much smaller than per capita differences between Australia and, say, Indonesia).

Table 1 *Kyoto protocol emission commitments*

Country	*Quantified emission limitation (per cent of base year)*
Australia	108
Canada	94
Croatia	95
Hungary	94
Iceland	110
Japan	94
New Zealand	100
Norway	101
Poland	94
Russian Federation	100
Ukraine	100
United States	93
Other Europe[a]	92

Note: [a] Refers to 23 European countries, including Baltic States. Also, the European Community as a distinct entity (party) committed to an overall emission limitation of 92 per cent.
Source: FCCC (1997; Annex B).

countries through emissions trading even without their commitment to reduction targets. However, although this situation has an implicit equity outcome, and by itself has the ability to draw developing countries more formally into the agreement, it should not be the only equity outcome considered for longer-run commitments. The remainder of this essay addresses these considerations more specifically.

4. Beyond Kyoto

One permit distribution rule that is especially attractive, in light of economic reality and political attitudes, calls for granting developing countries permits equal to their projected baseline emissions in the initial year of the treaty; this is often referred to as the 'No Harm to Developing Countries' rule (see, e.g., Edmonds *et al.*, 1995). Countries are not forced to sell permits, so a developing country can simply use all of the permits itself and incur no costs of mitigation. Those countries that do sell permits, however, would receive revenues in excess of their mitigation costs. This also contributes to solving the global warming problem by helping lower the net cost to industrialized countries. Thus, this approach enables developing countries to join in the agreement at little or no risk and to gain experience in trading in international permit markets.

The simulation of the 'No Harm to Developing Countries' rule in the context of the Kyoto Protocol is presented in table 2. The simulation is performed for some major industrialized, transitional, and developing countries (regions), and the results are indicative for all countries. The analysis is performed for a single year, approximately the first year the Kyoto targets are binding, and is indicative of implications for subsequent years. The analysis was performed with a non-linear programming model described in detail in Rose *et al.* (1998) and whose parameters are presented in Rose and Stevens (1993).

Table 2 *Benefits and costs in year 2010 of CO2 mitigation at Kyoto target levels allowing for permit trading and including developing countries*[a]

Country (area)	*Gross benefit of Mitigation*[b]	*Pre-trading*		*Post-trading*		
		Mitigation cost	*Net benefits*	*Mitigation cost*	*Value of permits*	*Net benefit*
United States	\$14.8	\$22.6	−\$7.8	\$4.5	\$9.6	\$.7
Canada	0.9	2.1	−1.1	0.4	0.9	−0.3
Western Europe	9.0	17.3	−8.3	2.6	7.1	−0.7
Russian Federation	2.0	0.3	1.7	5.0	−7.0	4.0
Brazil	1.3	0.0	1.3	0.6	−1.3	2.0
Central Africa	0.1	0.0	0.1	0.0	−0.1	0.2
Indonesia	0.4	0.0	0.4	0.4	−0.7	0.8
China	4.7	0.0	4.7	4.6	−8.5	−8.6
Total[c]	\$33.3	\$42.3	−\$9.1	\$18.1	\$17.6[d]	\$15.2

Notes: [a] All figures in billions of 1990 dollars.
[b] Gross Benefit of mitigation is the same for both the Pre-Trading and Post-Trading cases.
[c] Total may not add up due to rounding.
[d] Sum of absolute value of either permit purchases (positive entries are additions to cost) or sales (negative entries are offsets to cost).

All countries benefit from CO_2 mitigation, and these benefits are the same before and after trading (see column 1 of table 2). Mitigation costs for a system of fixed quotas are presented in column 2. Costs are especially high for the US, Canada, and Western Europe, who must control 30.8, 30.0, and 31.5 per cent, respectively, of their gross CO_2 emissions in 2010 in order to meet reductions below 1990 level stipulated in table 1 (abatement percentages increase due to growth in emissions over the 20-year period). The Russian Federation's low cost is due to a combination of merely having to meet 1990 emission levels and to projected low overall growth. The four developing countries (regions) have no abatement requirements.

Note that initially net benefits are negative for three of the four Annex I parties. However, all four developing countries benefit from the actions of their industrialized country counterparts.

Permit trading changes the picture dramatically. Total net costs are reduced by \$24.2 billion (\$42.3 minus \$18.1 billion) overall. The value of permit revenues/expenditures is \$17.6 billion. Given the flexibility of the system, countries are now able to reach the least-cost outcome resulting in overall positive net benefits of \$15.2 billion. Moreover, six of the eight countries now have positive net benefits, with the other two projected to have rather small net losses (see column 7 of table 2). Even if gross benefits were zero, all developing countries come out ahead since permit revenues exceed mitigation costs (subtract column 4 entries from column 5 entries).

Moreover, the benefits for each country represent a conservative estimate in the following way: the addition of other Annex I countries would generate more CO_2 mitigation, and since this activity is a pure public good, it increases benefits to countries already listed, as well as those joining in now and at a future date, without any increase in the abatement requirements of those countries. In addition, the inclusion of more developing countries than those listed continues to lower costs to Annex I countries. In sum, and this is the essence of the rationale for a truly global accord, the more countries involved, the higher the total benefit and the benefit to each country, and the lower the cost to the initial parties (even if the ensuing countries are not explicitly required to mitigate, but have the option to do so after more than covering their mitigation costs with permit revenues).[4]

Bolin has expressed concern about the accuracy of climate change benefit estimates, a view shared by most others, some of whom also question the accuracy of mitigation cost estimates. I do not claim pinpoint accuracy of my simulations either, but do suggest that even with some wide variation in the numbers, the analysis is able to support the general insights presented.

5. Concluding remarks

I also express concern regarding how some might interpret Bolin's statement that 'traditional cost–benefit analyses are hardly possible at this stage'. This should not be construed as implying that, because the benefits associated with preventing global warming damages are difficult to measure, they should be excluded from consideration. In fact, the very term 'burden sharing' detracts from the distinct possibility that net benefits of GHG mitigation are positive. Moreover, the burden of absorbing the full damage of climate change if no mitigation were undertaken could exceed the burden of mitigation. Simply put, the cost incurred in mitigation could very well be the lesser of the two evils.

It may also be helpful to place into perspective the possible implication from the foregoing analysis that a dollar's worth of benefits or costs are equivalent in terms of welfare or utility in industrialized countries and developing countries alike. This is not my intent. This point is often brought up in defence of developing country positions in such negotiations, and does dramatize their situation when net costs are positive (permit revenues fall short of total mitigation costs) or when net benefits are negative. But when net costs are negative (permit revenues exceed not only additional mitigation costs but total mitigation costs) or when net benefits are positive, it implies that the relative welfare gains for developing countries are relatively greater than stated.

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[4] There is some concern that involvement in Joint Implementation or a permits market will result in developing countries selling off their low-cost options during a 'pre-commitment' phase and being stuck with only high-cost options. There are factors relating to technology and compensation that can assuage these concerns, however (see Rose *et al*., 1997).

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How serious are the damages associated with global warming?

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As one of the 900 or so scientists who contributed to the IPCC Second Assessment Report, 1995, I welcome this opportunity to react to the comments of the distinguished former Chairman of the IPCC. I, personally, contributed to two chapters and was the reviewer of three more. However, although a participant, I have found myself increasingly uneasy when hearing, time and time again, that the report was the consensus of the 900 or so scientists. From my perspective there was no such consensus nor was there any serious attempt to pool the some 900 contributors, contributing authors, and reviewers, to see if a consensus was possible. Rather, the Report was the result of a process involving many individuals, perhaps with a variety of disparate views. The 'conclusions' of the Report, I understand, were drawn by only a handful of the 'leadership' and even that was done only with great difficulty.

Having painted a picture of an incomplete consensus process, let me quickly assert that the Report has much to commend it and I do not seriously disagree with its principal conclusions. There is almost surely movement toward a consensus on the science among climate experts that the warming is, at least in part, the result of human actions, although there are some very notable critics of this view. However, change is a part of the human condition and a 'scientific consensus' alone rarely provides a complete base for proper public policy.

In many respects the global warming issue has the statistician's classic decision problem. Society can make a 'type 1 error' of rejecting the null hypothesis that warming is not occurring, when in fact there is no change (no warming). In this case we could be undertaking costly but unnecessary actions to address a problem that did not, in fact, exist. Alternatively, society may be making a 'type 2 error' of accepting the null hypothesis of no change when, in fact, there is a change (warming). In this case, of course, mitigating and adaptive actions would not be taken.

Of course, for the economist, the issue does not end once the natural science is resolved. Rather the economic problem is just beginning. Suppose that warming is established with certainty. The question now is to determine whether this is a desirable or undesirable change from the human perspective: what are the aggregate costs and benefits and, perhaps, what is the distribution of the costs and benefits. It is widely assumed that warming will have a negative net global impact and some studies purport to provide conformation of those damages. Clearly, in a world with the infrastructure that has been customized for the 'base' climate, a change of climate is likely to generate some damages, since the infrastructure becomes increasingly inappropriate as the climate moves away from that base. However, the severity of these damages will be a function of the amount of climate change and the rapidity with which this change occurs. Slow, small changes in climate are unlikely to generate serious damages. Infrastructure can be gradually adapted to the new slowly changing climate at a rate more or less consistent with normal replacement. It is only if, somehow, the pre-warming climate were 'the best of all climates' for the humankind of this world that slow change necessarily would generate major net damages as the global system slowly moved away from this global optimum, regardless of the infrastructure. Furthermore, although environmental economists are fond of doing contingent value studies, few have been done to determine the welfare implications of warmer weather. In my own informal and highly unscientific questionnaire, 60 per cent of the respondents would be 'willing to pay' a positive amount for a warmer climate while the rest were indifferent, with no one willing to pay for a cooler climate.

An important issue is the effects of warming on temperate and boreal natural systems including forests and prairies, as well as on agricultural systems. Research undertaken here at Resources for the Future has shown that although warmer and dryer climate would generate damages in the US heartland to agriculture and forests, most of the damages could be mitigated by wise farm and forest management (Rosenberg *et al*., 1993). The choice of crop can be adapted to fit the changing weather patterns and research can develop new climate-adapted crops. Irrigation may be introduced thereby reducing the net damages. Forests may give way to prairies, but this would happen only slowly at the forest margin and with little serious consequence.

In many respects, however, the question of warming may be secondary to that of precipitation. In our US heartland study, the effect of a warmer and wetter climate, should precipitation increase significantly, would have been to increase the productivity of farms and forests alike. Since almost all climate models anticipate substantial increases in precipitation in the face of green-house-gas induced warming, a broad issue is how the increased precipitation would be distributed. But, it is difficult to imagine a wetter world in which little of the substantial increase in precipitation falls on forests and agricultural lands. A warmer and wetter result would improve the overall prospects of agriculture and forestry in much of the world. Furthermore, a recent article in *Science* (Farquhar, 1997) argued that high carbon dioxide levels 'increase effective rainfall'.

Recent research (Sohngen *et al*., 1996) and research in progress suggest that under the warming scenario forest volumes and timber availability would rise globally, even while timber prices declined. Furthermore, since most models predict larger temperature increases as one moves from the equator to the poles, the warming would occur in the temperate and boreal regions where it would probably have positive effects on agriculture and forests if accompanied by sufficient increases in moisture. Thus, from the perspective of land productivity the question in much of the world may be more one of precipitation than of temperature (Bowes and Sedjo, 1993).

In Bolin's comments, his discussion of damages is most interesting for its lack of specificity. His stress on damages due to extreme weather events struck me as strange since the concept that warming will generate more extreme weather events is, at this point, only a poorly tested hypothesis and certainly not a scientific 'consensus' emerging from the IPCC process. Also, the fact that insurance premiums have become very high, at least in the US, almost certainly reflects the huge increase in construction in coastal zones vulnerable to storm damage over the past 25 years. This activity was largely promoted and subsidized by government, which is now concerned that it has generated huge liabilities through its subsidized flood and disaster insurance. It is almost surely these considerations, rather than any clear evidence of an increase in extreme weather events triggered by global warming, that are raising private insurance rates. Finally, his discussion of 'major changes in broad vegetative types' of forests is correct for a markedly changing climate, but as suggested above, not alarming. The ecosystem functions of forests can be performed by a host of vegetative types (e.g., see J.P. Grime, 1997) and ecosystem function damages associated with changing forest types are likely to be small, especially if the climate change is gradual and modest.

Most revealing of Chairman Bolin's comments was his view on the seriousness of the damages generated by climate change. I would characterize him as being agnostic on the issue of climate warming generating damages. Bolin expressed reluctance to use benefit–cost due to our inability to quantify the damages since, as he concluded in his presentation to the European Association of Environmental and Resource Economics, 'we are not yet able to tell more precisely how "dangerous" a human-induced climate change (would be), nor will it be possible to deduce if such changes will come about within decades, or if it will be a slower and less threatening process'. His comments appear to reflect not only uncertainty about the magnitude of the warming effects, but also uncertainty as to the sign of those effects.

Such a conclusion by the (former) Chairman of the IPCC certainly deserves at least equal footing in the policy debate with the tentative conclusion of the IPCC about the state of the global warming science. Yet concerns that society does not know whether the damages are really 'dangerous', rarely appear in the climate mitigation debates. Despite the uncertainty as to the severity of the damages, negotiators at Kyoto undertook deliberations as if the august scientific bodies have unequivocally determined that the future of our planet is dependent on tough and costly controls to reduce carbon dioxide. While in his June remarks Chairman Bolin suggested that, 'We need, of course, to find out what impacts of global climate change are serious enough to justify concerted actions by the global society', many of our governments' appear to be willing to sacrifice 2–3 per cent of our GDPs, literally trillions of dollars, on a new crusade to reduce carbon emissions in order to mitigate global warming. Certainly there is something wrong with a process that is willing to incur trillions to deal with a phenomenon that has yet been determined to have negative impacts.

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Economic analysis and climate change

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This review of the state of the art on climate change provides an excellent opportunity to reconsider the appropriate role for economic analysis in general and benefit–cost analysis in particular in setting climate change policy.

I concur with Professor Bolin's statement that the use of benefit–cost analysis to set the policy target (regardless of whether that target is specified in terms of aggregate emissions or a concentration level) would be premature. Though I suspect this point is obvious to most observers who have studied the methods by which damage estimates are compiled, at the risk of belaboring the point let me reiterate a few reasons.[1]

Damage estimates can only be as accurate as the science which underlies those estimates. As Bolin acknowledges the science is still in its infancy. Large uncertainties not only involve the emissions–climate change relationship (for example, the role of clouds, the oceans, and the release of methane from the thawing tundra), but also the relationship between climate change and its consequences (for example, the health consequences of climate change and the adaptability of terrestrial and marine ecosystems to increased climate-related stress).

Most existing damage estimates are derived assuming a continuous relationship between concentrations and effects (Cline, 1992). In fact the ecological literature makes it clear that stressed ecosystems can respond in very discontinuous ways (Holling, 1973; Holling, 1986; Perrings, 1997).

The cost of being wrong is very asymmetric. While it is true that over-investing in climate control has its costs (Kolstad, 1996), they pale in comparison with the damages that could occur if the climate is irreversibly altered. And because we have so little historical information about how climate would be affected by temperature changes of the magnitude being forecasted, an irreversible alteration cannot be ruled out.

Setting the policy target on the basis of a maximization of the present

[1] This position seems very similar to the position taken recently by a group of American economists who met to consider the appropriate role for benefit/cost analyses in environmental and safety decision making. (Arrow *et al.*, 1996)

value of net benefits from climate change investments does not automatically take into account the intergenerational distribution issues (Toman *et al.*, 1995). Even if all the damage forecasts turn out to be absolutely correct (an unlikely possibility), future generations would not necessarily be adequately protected.

These considerations support using a broader social perspective to set the policy target.[2]

Cost–effectiveness analysis can play an indirect, but significant, role in setting the policy target by suggesting how compliance costs vary with possible targets. Such analyses already exists (see Richels and Edmonds (1995), for example) and could be helpful to the Conference of Parties (COP) process in sifting through the implications of various alternatives.[3]

To make absolutely clear the point of view that is being espoused here, I believe that the traditional approach which attempts to solve the intergenerational equity problem by modifying the objective function or altering the discount rate is misguided. Rather the best approach, in my estimation, is to allow the climate change policy target to become a constraint on the optimization process.

Many of the empirical studies on the cost of climate change control have come to the conclusion that a slow, delayed path of investment is the one which minimizes the present value of compliance costs (see the review in Weyant (1993). This is hardly surprising since a slower path allows for a more natural rate of capital turnover, takes advantage of technical progress, and recognizes the time value of money.

However it is important to recognize that those estimates do not point to the stronger conclusion that we should do nothing now. If investments are ultimately going to take climate change into account, it must be clear to investors that future reductions are expected. If no policy were adopted, investors would have no particular incentive to invest in technologies which would help the climate change situation as normal capital turnover occurred.

Allowing flexible timing can be made even more attractive if it is accompanied by economic incentive policies (such as tradable permits) which

[2] Although a broader perspective might be desirable in principle, whether the translation of that broader perspective into policy by the COP process is effective remains an open question. If the complexity of the politics which drives the process renders it ineffective, the quest for broader perspectives could become a justification for inaction.

[3] Constrained benefit–cost analysis could play a role as well. For each candidate target it would be possible to maximize the present value of net benefits subject to that concentration or emissions constraint. This approach would have the virtue of choosing the path that costs the least in the broader sense of damages avoided and compliance costs incurred. Whereas a traditional cost–effectiveness analysis considers only compliance costs, constrained net benefit maximization would take damage costs into account as well. Of course the same information difficulties which plague a process completely dependent on benefit–cost analysis would attend these estimates as well, but the consequence of imprecision would presumably be less severe since the imposed constraint would limit the adverse consequences for the planet.

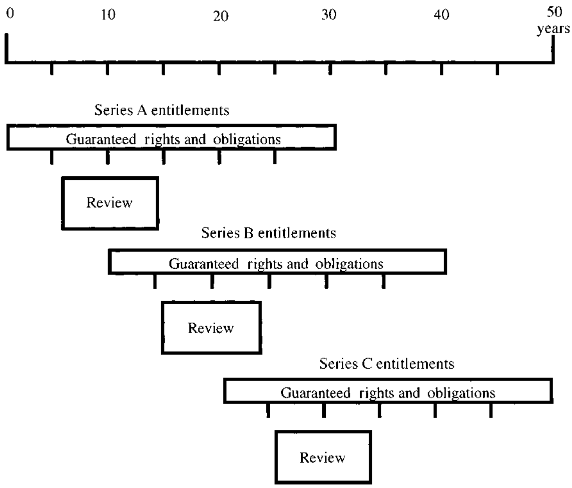

Figure 1 *Building resilience into climate change tradable permits*
Source: Based on figure 7.1 in Young and MaCay (1995)

increase the incentive to move as quickly as possible. With these approaches, even if emitters do not have to control gases early, they have an economic incentive to do so. Not only the ‘no regrets’ options, but strategies which go beyond that could become attractive.

Consider two conjectures which seem plausible: (1) the most important contributions to climate change will be made by future innovations and (2) economic incentive policies are particularly effective at promoting innovation. If these conjectures prove valid, then putting economic incentive regimes (such as tradable permits) in place now can promote the kind of action Bolin hopes for without the costs his most ardent critics fear.

Tradable permit approaches can also facilitate an adaptive management strategy (Young and McKay, 1995). One of the implications of the work of C.S. Holling is the importance of maintaining resilience in ecological systems. Furthermore since these ecological systems are characterized by constant change, it is important for the management regimes which govern the use of those resources exhibit resilience as well. They must be able to adapt flexibly to changing circumstances.

At the level of the firm tradable permits facilitate adaptive management. As new carbon reduction options (such as process changes, pollution prevention, fuel switching) materialize, tradable permits provide an incentive to make all cost-justified switches. Changing circumstances can be met with changing responses.

At the government level, however, the case is less clear. Here permit design must confront a fundamental dilemma. For permit markets to work well for global warming, they have to support investments in greenhouse gas reducing technologies. Firms are less likely to make those investments if they believe their emission entitlements are insecure. This suggests the need for specifying long duration (even perpetual) emission entitlements.

On the other hand, the need for a management regime which is adaptive suggests a process of entitlement definition which is flexible so that it can respond to better information and changing circumstances. Completely flexible entitlement definitions, however, underlie rather insecure property rights and hence can interfere with long-term investments.

Fortunately some resolution of this dilemma seems possible. One solution is to define the entitlement in terms of a share of a target aggregate emission level, rather than as a constant emission level (Godby *et al.*, 1997). This share, the entitlement, would remain constant over time, though the aggregate target to which it is applied could be adjusted by a predetermined process as circumstances merit. In fisheries, where this approach has been used for some time (Townsend, 1992), the aggregate catch level changes in response to prevailing biological conditions. In essence this shifts the risk from the ecosystem to the fishermen, but it does not seem to have interfered significantly with investment incentives.

An alternative approach to flexibility with security involves a cascade of fixed term entitlements, a variation of an approach currently used in the New South Wales fishery (Young, 1995). Under this scheme initial entitlements (call them Series A entitlements) would be defined for a finite period, but one long enough to encourage investments (say, for the sake of illustration, 30 years) (figure 1). The number of tons covered by the Series A entitlements would be known in advance.[4] Periodically (say, for illustration, every ten years) a comprehensive review would be undertaken which would result in a new set of entitlements (Series B, Series C, etc) which would also have a 30 year duration. Emitters holding Series A entitlements could have the option to switch to the new set of entitlements at any time earlier than the expiration of their Series A entitlements. Once they switched they would be able to hold Series B entitlements for their remaining life. This process would continue until such time as it appeared no more reviews were necessary.

In conclusion I believe economics has a very useful role to play in the climate change negotiations in clarifying implications of various choices and in offering a useful, flexible set of policy instruments to help convention framers achieve their agreed upon goals. That may not be the traditional role we have seen for ourselves, but it is a useful one.

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[4] The scheme is sufficiently flexible that entitlements could rise over time, fall over time or be constant. The main condition is that the time path be specified for the duration of that particular series.

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Burden sharing and adaptation beyond Kyoto: a more systematic approach essential for global climate policy success

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Bert Bolin gives an engaging overview of the findings of the Intergovernmental Panel on Climate Change (IPCC) with regard to the scale and speed of global warming, impacts of climate change, the choice between abatement and adaptation, and available policies and measures.[1]

[1] Prof. Bert Bolin was the chairman of IPCC until September 1997.

In this comment I address three issues that deserve more attention than so far given to them. These issues are (1) international and national burden sharing, (2) adaptation as a policy measure, and (3) policy choice and burden sharing between north and south. These issues rise important challenges for future research that should be addressed to improve our ability to develop and implement an efficient and fair global climate policy.

1. International and national burden sharing

The Kyoto Protocol to the United Nations Framework Convention on Climate Change was signed on 11 December 1997 in Kyoto, Japan. It is only one step in a global climate policy process ahead of us. According to the Kyoto Protocol industrialized countries agree to reduce their emissions of six greenhouse gases by at least 5 per cent in the period 2008–12 compared to the emission level in 1990. The national targets are differentiated between +10 per cent (for Iceland) and −8 per cent (for the European Union (EU), and for some other countries). EU has an internal differentiation scheme that adds up to −10 per cent compared to 1990 emissions. This scheme has to be re-negotiated given the new −8 per cent target and the inclusion of three more greenhouse gases in the Kyoto Protocol than anticipated. The EU differentiation range is from +40 per cent for Portugal to −30 per cent for Luxembourg. The target for Germany, Denmark, and Austria is −25 per cent. So far there are no binding targets for developing countries in the Kyoto Protocol. Targets for the next five-year budget period will be negotiated later. Sooner or later commitments for developing countries have to be negotiated if we are to be able to control global emissions of greenhouse gases. The first step could be voluntary commitments for these countries.

One interesting feature of the Kyoto Protocol is the opening for differentiated commitments. This type of burden sharing is likely to be vital for future target negotiations and for later commitments for developing countries.

During the Kyoto Protocol negotiations different burden sharing equity principles, criteria, and formulae were proposed, but the final scheme was only based on each country's willingness to undertake emission reductions during the last turbulent negotiation sessions, dominated by the three main Parties the US, EU, and Japan. For future negotiations a more systematic approach to burden sharing can avoid many of the pitfalls of the 'willingness to reduce' approach from Kyoto, for instance incentives to free riding. A more systematic approach to burden sharing could also induce the participation of developing countries. Therefore more research resources should be spent on developing systematic differentiation schemes, which could partly be based on ethical principles (that in some ways can be made operational), and partly on empirically based criteria such as base-year emissions per capita, gross domestic product per capita, etc. One of the challenges in such a project is to agree on some universal equity principles given the substantial variation in social and political values among the nations of the world.

A related burden sharing issue that is paid too little attention is the burden sharing implications within a country of implementing agreements like the Kyoto Protocol. Ambitious reductions of greenhouse gas emissions will necessitate structural changes within a country. The consequences for a country also depend on the choice of policy measures, for example carbon taxes, emission permit trading, or environmental agreements. Implementation of a national abatement target with a specific set of policies will distribute the cost or burden between socio-economic groups, industries, and local communities in a specific way. An alternative choice of measures may have other burden sharing consequences. We also know that industries and other resourceful groups that are vulnerable to such policies in the sense that they (think they) are facing a disproportional part of the costs, have a large influence on this implementation process. The challenge is to find efficient strategies of implementing international environmental agreements that are considered reasonably fair by all groups to avoid unnecessary confrontations that increase the implementation cost and may compromise the citizens' willingness to support an efficient global climate policy.

2. Adaptation as a policy measure

Given the global warming scenarios described by IPCC we will only be able to stabilize the greenhouse gas concentrations in the atmosphere at a level that is substantially higher than the pre-industrial level, even if sizable emission reductions are implemented. This means that we are committed to some global warming, but uncertainty relates to the scale, variability, and speed of warming. Furthermore this means that some adaptation to climate change is unavoidable. According to IPCC (1996) p. 831, adaptation 'refers to any adjustment – whether passive, reactive or anticipatory – that can respond to anticipated or actual consequences associated with climate change …'. If all the relevant information was available the optimal policy mix of emission abatement, adaptation to climate change, and residual damage from climate change could be characterized by undertaking abatement and adaptation measures until the marginal cost of each of these policy types are equal, and furthermore equal to the residual marginal damage cost.

Adaptation is an important policy type that IPCC so far has paid too little attention to. As Bolin mentions we need cost estimates for both abatement and adaptation measures. So far there has been much more research activity on abatement than on adaptation. One of the challenges of estimating adaptation costs is that the society and ecosystems change all the time, and will to some extent 'automatically' adapt to climate change. In addition adaptation measures may be seen as a type of climate change cost since they are a response to anticipated or realized climate change, with the aim of lowering the damage from climate change.

Both for abatement and adaptation measures the best options lead to 'win–win' situations. For abatement measures this can mean investments in increased energy efficiency that reduce emissions of greenhouse gases and local air pollutants. For adaptation measures this can mean emphasis on measures and projects that are flexible with respect to the different climate futures possible. Thus climate flexibility should be built into long-term investments in infrastructure and buildings, increasing the adaptability and lowering the vulnerability of such constructions with respect to future climate change. Such investments may also pay off if only a minor climate change should occur since an increased adaptability is likely to have a value with respect to natural weather variations. My guess is that climate flexibility considerations can be built into investment plans at a small cost, but can save considerable climate change damage costs in the future. More research on costs and benefits of such adaptation policies is needed to come up with reliable figures.

3. Policy choice and burden sharing between north and south

There are some interesting features of abatement and adaptation, on the one hand, and burden sharing between developing countries, and industrialized countries, on the other hand. This may be framed as a game between developing countries and industrialized countries on the choice of a global climate policy. If developing countries are too reluctant to take on commitments to abate their emissions, industrialized countries may switch the focus from abatement to adaptation measures. Industrialized countries can claim that their abatement efforts are of small value as long as developing countries' emissions are not controlled. Emphasis on adaptation measures will not reduce global warming, but reduce the damage costs to the society (and possibly the nature). There will be very small free rider problems associated with adaptation since a country is able to reap most of the benefits alone, as opposed to abatement measures, where the effect only depends on the collective effort. Add to this that developing countries are more vulnerable to global warming and are likely to have lower adaptability than industrialized countries. Thus industrialized countries may use emphasis on adaptation as a credible threat to induce developing countries to take on commitments to reduce their emissions of greenhouse gases. The challenge for developing countries is to balance between delaying commitments, where they rightly argue that industrialized countries have the moral responsibility and financial capacity to take the first steps, and accepting new commitments to induce industrialized countries to keep up emission abatement ambitions. If they are too reluctant to take on commitments they risk industrialized countries switching to adaptation and leaving most of the bill to be paid by developing countries.

The strategic situation and differing interests of developing countries and industrialized countries in terms of choice of a global climate policy strategy is a vital background for future Kyoto Protocol negotiations. The challenge is to develop targets, burden sharing schemes, and implementation strategies and measures that are considered both reasonably fair and efficient by developing as well as industrialized countries.

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