International Approaches to Global Climate Change

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I. Introduction

Human activity since 1800 has resulted in the emission of great volumes of gaseous materials into the atmosphere. Some of these gases -- notably carbon dioxide, methane, and chlorofluorocarbons (CFCs) -- absorb the earth's radiation, leading potentially to a warming of the earth's surface, which in turn could alter the earth's climate. At the molecular level, CFCs are the most potent "greenhouse gases;" but carbon dioxide has been emitted in greatest volume, largely from clearing forests and from burning coal and oil, and has the longest life in the atmosphere, thus accumulating over time. Atmospheric concentration of carbon dioxide in recent years has reached 360 parts per million (ppm), compared with about 280 ppm around 1800, and on some current projections is headed to 700 ppm (two and a half times pre-industrial concentrations) by 2100 (CEA, 1998, p.18).

Wide scientific consensus suggests that under these conditions the earth's surface will become warmer on average, with temperature increases being higher in the higher latitudes. Sea levels will also rise, due partly to melting glaciers but mainly to thermal expansion. And average global precipitation will increase.

Beyond these general effects the consensus dissipates. The earth's atmospheric physics and chemistry are complicated and not well understood; nor is the relationship between the atmosphere and the oceans, or between climate and the biosphere (all forms of life). Thus there is little agreement on the rate at which carbon dioxide is taken out of the atmosphere by chemical or biological processes, on the influence of greater warming and evaporation on cloud formation (which affects the extent to which the sun's rays are reflected away from the earth's surface), on the rate at which the oceans absorb heat from the atmosphere, and on a host of other relevant issues. Thus there is little agreement on either the ultimate extent or the pace of warming for any given trajectory of greenhouse gas emissions.[1]

Neither is the future trajectory of emissions known with high confidence, although continued "business as usual" economic growth can be expected to result in ever greater consumption of fossil fuels for many decades. The IPCC (1996b) assumes in its main "business-as-usual" case a global growth in emissions of carbon dioxide of 1.1 percent a year over the period 1990-2100. On this assumed path of emissions, the generally accepted range of warming over the course of the next century is 1.0 - 3.5NC, with a best guess being perhaps 2.0NC, and an equivalently uncertain rise in sea level centered on about half a meter, in the absence of actions to reduce substantially the growth of greenhouse gas emissions.[2]

Confronted with these possibilities, the international community agreed at Rio de Janeiro in 1992 on a Framework Convention on Climate Change (FCCC) and at Kyoto in 1997 on a Protocol that committed the FCCC's Annex I countries (the 24 1995 members of the Organization for Economic Cooperation and Development (OECD), central and eastern Europe, and the successor states to the Soviet Union) to reduce emissions by the year 2012 to estimated 1990 levels or up to 8 percent lower, with the targets varying from country to country.[3] The Protocol has not yet come into force, and indeed the US government indicated it would not submit the Protocol for Senate ratification until "significant participation" by leading developing countries was assured, as requested by Senate resolution.

This paper will take up successively the social and economic impacts of climate change (section II), the framework for inter-governmental collective decision-making (section III), the question of burden-sharing (section IV), compliance (section V), possible national steps toward mitigation (section VI), and contingency planning (section VII).[4]

II. Social and Economic Impacts

It is of course difficult to specify with any confidence what the economic and social impacts of climate change will be without knowing either the extent or the detailed nature of the change in climate. There has been extensive speculation about the possible malign effects of climate change, and some serious attempts to estimate the economic effects in particular regions or globally. These latter efforts are necessarily parametric, most commonly but not universally assuming a rise in global mean temperature of 2.5◦C or so over the next century. Assumptions are also made about other possible consequences of climate change on which there is no scientific consensus, such as the frequency and magnitude of major storms (a smaller latitudinal temperature gradient would, other things equal, tend to reduce serious storms, but a larger altitudinal temperature gradient might increase them, so the IPCC scientists are agnostic on this point), or the regional and seasonal distribution of the increased precipitation. Such "details" are of vital importance to the impact on society, determining even whether climate change will on balance be malign or benign.

Several key potential economic impacts have been identified. Perhaps the most important is the impact on agriculture -- world food production. In addition, concerns have been expressed about health (both the spread of disease, and other health conditions), about the impact of rising sea levels on coastal areas, and about the general amenity of life, including comfort and recreational possibilities. In addition, concerns have been expressed about non-human ecological communities. Something will be said about each of these.

Agriculture. The impact of climate on agriculture depends intimately on the detailed effects of climate change, particularly the regional and seasonal changes in precipitation. But whatever adverse effects (if any) might occur under that heading must be measured against the fact that plants rely on carbon dioxide as a major input to their production, such that increased atmospheric carbon dioxide, taken alone, would actually increase agricultural yields; and against the fact that agricultural producers around the world, but especially in temperate zones, have a demonstrated capacity for adaptation to a variety of changes in their (economic as well as physical) environment. Comprehensive work on agricultural response to global climate change is still in an early stage, but several studies suggest that changes of the likely magnitude will not have a significant effect on global food output, although there might be significant impact at the regional level. For example, Schimmelpfennig et al. (1996), drawing on the work of others, show that 20-30 percent declines in output of grains at two locations in the United States under substantial (4-5NC) increases in temperature are greatly moderated, or even converted into increases, with plausible adaptation by farmers; allowance for the CO_2 fertilization effect would assure increases for all three products: maize, soybeans, and winter wheat (cited by Reilly in Nordhaus, 1998, p.246). Similarly, Darwin et al. (1995) show that under four climate models with a doubling of atmospheric carbon dioxide declines in global production of cereals become modest increases when farmer adaptation and market adjustments are allowed; small declines in non-grain food production are more than offset by increases in cereal and livestock (Meyer et al. in Rayner and Malone, vol. 2, 1998, p.130-31). Table 1 shows the difference that economic adjustments and adaptation can make in four models. Increases in cereals production become more substantial (plus 10-15 percent) when CO_2 fertilization is allowed for.[5]

While global food production does not seem to decline with global warming -- on the contrary -- the regional distribution is not even. In particular, production rises in the higher latitudes, due partly to an increase in arable land; and tends to fall in the tropics, due mainly to an assumed decline in availability of water. But the uncertainties must again be emphasized, particularly regarding regional effects, where the global climate models, which provide the basis for most forward-looking projections, reveal substantial variation from one to another.

Disease. Some observers have expressed concern that global warming will increase the threat to humans from contagious diseases, which tend to thrive more in warm climates than in cool ones. In particular, the potential range of endemic malaria, which continues to resist being subdued, will be extended as the relevant insect vector is able to move further north and south from the equator.

The extension of the range of tropical and sub-tropical diseases is unquestionably a legitimate concern. But again, adaptation of human society to such extensions must be contemplated; on past experience, humans are not simply going to accept increased spread of disease without strong reaction. It is well known that much more medical and pharmacological research is devoted to temperate diseases and health conditions than to tropical disease, largely because today's rich countries are mainly in temperate latitudes and they understandably pay most attention to the health conditions that most concern their residents. If malaria or other tropical diseases were to extend into these latitudes, one can forecast with high confidence that many more resources would be devoted both to stopping the spread of the diseases and to immunizing the population against them. Advances in genetic engineering give high confidence that most diseases can be overcome, or at least kept under control.

Moreover, the world economy will continues to grow; indeed, that is a key assumption underlying the projections of carbon dioxide emissions. Even a modest growth of one percent a year in global per capita income will result in a 170 percent increase in incomes over a century; a more likely 1.5 percent growth would increase global per capita income by a factor of 4.4, with even more rapid growth in many regions that are now relatively poor. Increases of income enlarge the possible and likely human reactions to all aspects of their environment, including threats from disease. Malaria is virtually unknown in Singapore, near the equator, while it is common across the border in Malaysia. The difference is attention paid to keeping mosquitos from breeding, and to keeping them from biting at night, e.g. through screened bedrooms or interior air conditioning. Greater wealth leads to better capacity to control one's environment, both by individuals and by society.

Coastal inundation. A rise in sea level will of course affect the habitability of coastal areas, where much of the world's population lives. A half meter rise in sea level is not much, but when allowance is made for storm surges it could make currently inhabited areas uncomfortable, or even in extreme cases uninhabitable. Nicholls et al. (in Nicholls and Leatherman, 1995; cited in Rayner and Malone, vol. 2, 1998, p.180) estimate that five percent of the world population would be affected, with one percent of those put seriously at risk. As with food production and disease, however, humans are not simply going to endure an adverse change; they will attempt to protect themselves against it, by some combination of moving away, accommodating their structures and behavior, and protection against inundation.[6] Nicholls et al. estimate that a combination of such measures will reduce the population at risk by 88 percent, to 0.14 percent of the world population. Adaptation measures are estimated to cost annually .056 percent of gross world product, i.e. little more than 1/20 of one percent. Of course, there are substantial regional variations in cost, with protective measures being three quarters of one percent of GDP in the small Indian and Pacific Ocean island nations, and only one-hundredth of one percent on Latin America's Pacific coast.

Market Impacts and Amenities. Various attempts have been made to provide an overall assessment of the costs of climate change, and controversy surrounds the process, particularly the objection by some non-economists at the insistence of economists on valuing the expected changes at market prices or something approximating them, and the disagreements among economists on how best to do this. This is not the place to review this extensive and somewhat confused literature, only to note that human behavior guided by foresight, or even by expectations based on one or two unpleasant experiences, can do a great deal to mitigate the costs of global climate change. To assume that people remain both ignorant and passive in the face of change is, on the face of it, absurd; the entire international process involving the IPCC, the FCCC, and the Kyoto Protocol demonstrates that people are capable of thinking ahead and acting in anticipation -- although not always wisely!

The emerging literature suggests that the best-guess costs associated with global warming are likely to be low, not catastrophic, as popular treatment of the subject sometimes suggests. Table 2 compiles the results from three studies, all assuming an average increase in global temperature of 2.5NC. It suggests a range from a net cost of 0.7 percent of gross world product to a net gain of nearly 0.1 percent.[7] Again the regional disparity is noteworthy, with OECD countries experiencing a net gain in the more recent Mendelsohn study, with very slight adverse change for non-OECD countries, to roughly equal losses in the older Fankhauser study.

Moore (1998) has attempted to assess both the measurable and the not-so-easily measurable gains and losses for the United States arising from global climate change. He concludes, somewhat to his own surprise, that the United States is likely to be a net beneficiary of climate change -- a result that would be even clearer for more northerly countries such as Canada and Russia.
In particular, he argues that health is likely to improve in a warmer climate, that daily life would be more pleasant, and that recreational possibilities, while altered, would be altered in ways that cater more to current revealed preferences for recreation.

A similar conclusion has been reached by Mendelsohn and Neumann (1998), who report substantial revisions to earlier estimates of the costs of global warming to the United States, toward lower sectoral costs or even benefits -- with net benefits amounting to 0.2 percent of 2060 US GDP for a global warming in the range 1.5-2.5NC and modest increase in precipitation (Tables 12-2; 12-3).

Of course, reducing stack and auto exhaust emissions to avoid climate change will also reduce emissions of other substances, such as nitrogen oxides and small particles. Reduction of these ancillary emissions, by reducing urban air pollution, will produce some positive health benefits.

The possibility that some countries may actually gain from climate change potentially complicates greatly the prospects of reaching global agreement on measures to limit climate change.

<u>Non-human ecological systems</u>. While human beings have demonstrated a remarkable capacity for adaptation to a variety of conditions and new developments, the same cannot be said with respect to all others species. Some single-celled creatures and some insects have also demonstrated high capacity for adaptation. But climate change that occurs with rapidity may find many species unable to adapt in the time required.

In addition to affecting human settlements, rising sea levels will also affect natural eco-systems, and in particular wetlands, known for their high biological activity. Moreover, some human adaptation may come at the further expense of wetlands. Nicholls et al. estimate, for instance, that without countervailing measures 56 percent of the world's wetlands will be adversely affected by rising sea levels, and that this figure rises to 59 percent once allowance is made for measures to protect human settlement (from Rayner and Malone, vol. 2, 1998, p.180). However, it must also be recognized that existing wetlands are in rapid decline for reasons that have nothing to do with climate change. If wetlands are to be preserved, affirmative human action will have to be taken, whether or not climate change threatens them.

Warming of middle and northern latitudes will alter the natural vegetation, and that in turn will alter the natural fauna. But trees take a long time to grow, and species move in nature only as rapidly as seeds can be carried by wind or creatures into newly habitable territory. However, human agency need not be limited to human adaptation to climate change; humans can also assist other species to adapt to the new conditions, provided the requisite knowledge is available, and provided the issue is considered sufficiently important to attract the requisite attention and resources.

Speciation is much higher in the tropics than in higher latitudes. Micro eco-systems flourish in the tropics and highly specialized plants and especially animals with limited range have developed. Fortunately temperature increases are likely to be least in tropical zones. But changes in patterns of precipitation and CO_2 fertilization will lead to some alteration of these eco-systems, permitting some species to flourish at the expense of others, possibly driving some to extinction.

III. Framework for Collective Decision-making

Concerns about global climate change have led to pleas and indeed to some national commitments to slow or reverse the growth of greenhouse gas emissions. It is useful to identify the structural characteristics involved in attempting to mitigate global warming through formal collective action. There are three key features:

First, climate change brought about through an increased atmospheric concentration of greenhouse gases is a <u>global</u> issue, since whatever their earthly origin the gases are widely dispersed in the upper atmosphere. Effective restraint must therefore involve all (actual and prospective) major emitters of greenhouse gases. Today's rich industrialized countries account for most of the emissions today, but the Soviet Union was a major contributor before its dissolution and economic collapse in 1991, and can be expected to become a major source with economic recovery. Rapidly growing developing countries will become major contributors within a time frame that is relevant for managing the issue. By 2010 developing countries are expected to contribute 45 percent of total greenhouse gas emissions, and China and India alone will experience greater growth in emissions than all OECD countries combined. Thus effective action cannot be taken by a small group of countries alone, as was possible for example with agreement to cease atmospheric testing of nuclear weapons. Here, while the same requirements need not be imposed on all countries from the beginning, the agreement needs to be structured so that all countries will eventually participate. On one estimate, for example, full implementation of the Kyoto Protocol and continuation at the prescribed lower emission levels of Annex I countries would, on IPCC main assumptions, reduce the increase in average global surface temperature in 2050 by only 0.05NC, from an increase of 1.4N to 1.35N.[8]

Second, the rewards from restraints on greenhouse gas emissions will come in the (politically) distant future, while the costs will occur in the political present. Moreover, the rewards are highly uncertain. As the discussion in Section II suggested, much controversy still surrounds the expected impact of further greenhouse gas emission on the earth's ecological system, and in particular on conditions of habitability for humans. The residents of some of today's states, e.g. Canada, Russia, perhaps the United States, may even expect to benefit from moderate climate change. It will thus be difficult to persuade publics that they should make sacrifices in living standards in the near future for the sake of uncertain gains to their grandchildren and great-grandchildren. The wide distribution of expected but distant benefits in response to collective action today provides an incentive for every country to encourage all to act, but then to avoid acting itself -- the so-called free-rider problem.

Third, the pervasive sources of greenhouse gas emissions -- notably use of fossil fuels, rice cultivation, and raising cattle -- imply that restraint will involve changes in behavior by hundreds of millions if not billions of people, and not merely the actions (or restraint in action) by 180 or fewer governments, as in the typical treaty. Thus the most important part of an effective regime to limit climate change involves not the relationships among states, but the effective influence of governments on the behavior of their domestic publics.

No major legally binding regulatory treaty involves all of these characteristics to the same degree. Typically either governments themselves are the major actors, or a relatively few firms in a relatively few countries, as in the cases of halting nuclear testing or limiting production of CFCs. The Convention on International Trade in Endangered Species perhaps comes closest in its comprehensiveness; it requires states to prohibit international trade in an agreed list of products. The Chemical Warfare Convention is extremely intrusive in its monitoring requirements, but has not yet come into force. The various agreements for management of international fisheries require cooperation of hundreds of fishermen, but with a few exceptions they have not been notably successful.

These three structural factors make collective decisions regarding actions to mitigate global climate change exceptionally difficult. The benefits of mitigation actions encompass the adverse impacts of climate change that are thus avoided. Serious mitigation necessarily involves major reductions in the actual and prospective consumption of energy based on fossil fuels (especially coal-fired electricity generation and use of oil products for heat and motive transportation). Since such consumption is at the very heart of modern industrialized economies, the costs of mitigation are both the economic and the psychological adjustments that must be made to move away from current energy systems; and, secondarily, the adjustments that must be made to move away from wet rice and cattle production, the main man-made sources of methane (in addition to methane leaks from gas and oil refining and distribution systems).

It is natural for an economist to compare the benefits of any proposed change with the costs required to make the change. Many non-economists reject cost-benefit analysis, as being an artifact of calculators who ignore or underrate basic human values. But this rejection is simply an intellectual mistake; everyone who urges a change in policy (or resists one) is at least implicitly comparing costs with benefits. The disagreement rather is on how best to measure the alleged benefits and the costs of the proposed change. Thus when Krause, Bach, and Koomey (1992) argue that on no account should the average global temperature be allowed to rise more than 2.5NC, the outer limit of the earth's temperature in the last 2 million years, and that worst plausible case calculations suggest that means a maximum of 300 million tons of additional carbon can be emitted into the atmosphere, they are implicitly arguing that the benefits of severe mitigation action are infinitely great, and that any finite cost to achieve them is thus warranted. They are expressing an extreme degree of aversion to environmental risk. Others may properly disagree with such extreme valuation. The frequently advocated "precautionary principle" as applied to greenhouse gas emissions reflects similar risk averse sentiment, while perhaps not taking it as far as Krause and his colleagues do.

Table 3 illustrates the range of marginal benefits per ton of carbon emission avoided, and the range of marginal costs of reducing emissions by a ton of carbon for two different targets: a return to 1990 emissions and a 20 percent reduction from 1990 emissions. All the estimates must be taken as illustrative, as the methodologies for making them are quite different and are incomplete. With this caveat, they suggest that costs generally exceed benefits, especially for reductions in emissions. The wide variation suggests the methodology for estimating costs and benefits can stand considerable improvement. The costs of reducing emissions not surprisingly rise with the magnitude of the reductions. Stavins (1998) for carbon sequestration in the United States and Kram (in Nordhaus (1998), p.186) for four technologies in the Netherlands suggest that the increases can be very steep.

The Discount Rate. Actions to mitigate climate change by cutting greenhouse gas emissions involve incurring costs long before the benefits are registered. To compare near-term costs with future benefits requires a discount rate (or stream of rates) to put both into present value. Much has been written about the appropriate choice of a discount rate,[9] and the principles that should undergird the choice. Theoretical and some practical economists have been fascinated by the Ramsey model of savings, which suggests that the optimum social rate of time preference (r) can be expressed by the simple equation $r = \rho + \theta g$, where ρ is the pure rate of time preference, θ is the elasticity of marginal utility with respect to additional consumption, and g is the growth rate of per capita consumption.[10] Plausible numbers for these variables that have been advanced lead to discount rates ranging from 0.5 to 3 percent (see IPCC (1996), pp. 131-32).[11]

I confess to being simply baffled by this debate. The underlying rationale for thinking about avoiding or mitigating climate change is to benefit future generations relative to what would be the case with climate change. Yet to undertake investments in the near future that yield, say, 2 percent over the next century does a great disservice to future generations compared with other investments that we have strong reason to believe yield much higher returns many years into the future, if not for an entire century. We should surely, in the interest of future generations, prefer high return investments to low ones.

There is evidence that returns to education in developing countries exceed 20 percent (Psacharopoulos, 1985, 1994). Returns to college education for a male in the United States reportedly equal 13 percent (CEA, 1996, p.198). A study of over 1000 projects completed by the World Bank in the 1970s and 1980s yielded an average (prospective) return of 16 percent (Pöhl and Mihaljek, 1989). The World Bank and the US Government have stated threshold returns of ten percent for evaluating prospective investments (recently reduced to seven percent by the US government). The corporate sector of the US economy, one that is relatively rich in capital by global standards, yields an average pre-tax real return well over ten percent. For all these reasons, I believe that ten percent is a reasonable rate of discount. A high discount rate of course gives less weight to benefits (and costs) in the distant future. But that implication alone is not sufficient reason to reject it.

Maurice Scott of Oxford University has suggested four percent (reported in Beckerman, 1996), partly on grounds that that has been the real yield on low-risk government bonds in recent decades. But that would be a mistake: even if we can extract resources from the public at four percent, we should invest in those activities with high (social) return. Only after we exhaust ten and seven and five percent opportunities should we accept investments with prospective yields of only four percent. Otherwise we deprive either future generations or our generation unnecessarily.

Some observers object to citing data on observed rates of return on grounds that actual decisions made today and in the past have not been made under ideal conditions, and have reflected a number of imperfections both in markets and in our processes for making collective decisions. It would take us too far afield to explore this contention in relevant detail. Let us just stipulate that by any given set of ideal standards, the real world is messy and actual decisions (and market outcomes) deviate from them. What bearing does that have on the issue at hand? The same observation will apply to actions to mitigate greenhouse gas emissions. A plausible argument must be made that allowance for the various imperfections will raise the after-the-fact returns to mitigation actions relative to the observed returns on other investments.

The debate over the choice of a discount rate to be applied to mitigation actions can be interpreted as an effort to reduce or eliminate imperfections in collective decision-making on public expenditures in general. But if such imperfections exist and are important, and if other public investments seem to leave future generations still better off, why do not the advocates of low discount rates apply their arguments to those higher yield investments? Some of them no doubt do, but those that do not must fail to do so either because they believe the political prospects are better for improving collective decision making in the arena of global climate change than for other, higher yield public investments, and/or they must prefer mitigation of greenhouse gas emissions on some different and generally unstated grounds, not captured in the usual reckoning of costs and benefits over time, and want to develop any argument that tends to support such actions. In either case, it would be useful and desirable to open these considerations explicitly to wider discussion.

This sounds like common sense. What can be the objection to it? One possibility is that while in the near future the return on investment class A (education, say) exceeds that on investment class B (mitigation), in the long run the reverse is true, because of a secular decline in returns to investment class A. Normally one could switch to B investments as returns to A drop below those to B. The preference for investing in B now would occur only if for some reason it would be too late to switch to B investments later, after returns to new A investments fell.

This type of configuration is theoretically possible, but it is necessary to make a plausible case for both parts to conclude that we should reject A in favor of B at the outset. In the standard neo-classical economic model the returns to capital are assumed to fall steadily as the ratio of capital to labor (and other factors) rises. But in historical --as distinguished from analytical-- time technical change has constantly increased the returns to (new) capital, and there is no reason to believe that that process will stop during the next century. Thus if returns to class A are high now relative to B, they are likely to remain so.

<u>Distributional considerations</u>. The IPCC (1996a, chapter 4) authors seem to reject the efficiency argument that is emphasized here, not on the foregoing grounds, but on the basis of equity. We cannot ethically say that investment A is superior to investment B even if it yields higher total future benefits if those persons who experience losses as a result of the investment are not actually compensated (in the absence of a social welfare function that indicates the relative weights we should attach to winners and losers).

This is a logically valid point. But if taken literally and applied seriously, it is a prescription for total inaction, especially when time frames as long as 100 years are under consideration. Again, it defies common sense.

First, we do not have a collectively agreed social welfare function, and we have no prospect of agreeing on one at a global level, so we cannot generally weigh winners against losers, especially over so long a time period.

Second, we cannot possibly know distant future winners and losers from our actions today (try, for example, to identify with reasonable accuracy the winners and losers from completion of the US continental railroad in 1869, or to forecast the winners and losers one hundred years hence from construction of the Three Gorges Dam in China).

Third, we cannot bind future generations to adhere to our preferred outcomes even if we could have the requisite knowledge about future winners and losers and our preferences among them. If we make rules, future generations can unmake them. If we plant trees, they can cut them down. If we consume less coal, they can consume more -- and may actually do so because it is more readily available to them. The one legacy which we can leave that is impossible to reverse (short of a collapse of civilization) is enhanced knowledge, both a deeper understanding of nature and improved technology.

We should be concerned above all with passing to the next generation more knowledge and higher incomes than we received, and allow its members to decide how to distribute them. They will so in any case, regardless of what we think.

This is not to suggest that we should be completely indifferent to distributional effects. Our actions will affect the initial distribution of the next generation, and collectively we may want to avoid certain actions on grounds that we do not like their distributional effects. But here I mean the direct next generation consequences of our actions, on which it may be possible to get collective agreement on avoiding extreme losses being imposed on certain classes of people. But we cannot carry this logic into the more distant future on the grounds already mentioned: we cannot possibly know the distant future impact on people (for one thing, we do not even know where they will be), and we cannot commit future generations to our preferences even if we did.

In any case, it is rather odd to urge costly action now for the sake of poor people in the distant future when we are not willing to take very costly action now for the sake of reducing poverty today. We have actual evidence on the amounts we are willing to spend, individually and collectively, in the name of reducing poverty in today's poor countries: about 0.3 percent of GDP of the rich countries. If we are really concerned about the impact of possible future climate change on poor people, we should take more active steps to reduce their poverty systematically, which in principle we now know how to do. That would improve their capacity to adapt to such climate changes as may take place, and to take mitigation actions themselves.

If there is a general disposition within the rich countries to help people in poor countries, the best way to do it is probably through education. Education has at least three advantages with respect to mitigation of climate change. First, the rate of return seems to be substantially higher, at least on the estimates that have been made so far. Second, it is harder for future generations to undo the redistribution thus favored by this generations, since educated parents are likely to want to see their children educated. Third, great education increases the capacity of any society, and of individuals, to adapt to changing circumstances, including but not limited to changes in climate.

Risk Aversion. It is widely taken for granted, at least on big issues, that people dislike uncertainty; they have an aversion to risk, and are willing to pay something to reduce risk. This is the attitude that underlies the willingness of individuals to take out fire or liability insurance, to pay a certain known cost (the insurance premium) to mitigate the possible costs of uncertain and perhaps even improbable unfavorable events. The conflagration of one's house is a costly event, but the costs are at least partly offset by a payment by the insurer.

The uncertainties associated with mitigating global climate change and its attendant costs are in the current state knowledge at least as great -- probably greater -- than the uncertainties associated with other forms of investment that we could undertake today, and on that account, given risk aversion, it will perhaps be concluded that costly mitigation actions should not be undertaken. However, the payoff from mitigation actions now will be greatest if the magnitude of global climate change and the associated costs turn out to be high, even if that is judged to be a contingency of low probability. Of course, if the costs associated with global climate change are low, any investment in mitigation actions will have a low or negligible return. But such investment may still be worthwhile as insurance against an uncertain but possibly costly contingency.

How do these considerations influence the discount rate? The precise answer is not at all straightforward, unless the uncertainty itself is related in a particular way to the passage of time. Roughly speaking, however, one can say that where an uncertain outcome (the future payoff from mitigation actions) is negatively correlated with our overall economic prospects, and where the uncertainty grows exponentially with time, some deduction from the discount rate used to evaluate mitigation actions is warranted. How much? That depends in detail on the nature of the uncertainty, an issue that needs much greater discussion, and on the degree of our aversion to risk. But presumably it was this sort of consideration that led US policymakers in 1980 to stipulate a discount rate of only seven percent for publicly financed energy-related projects, three percentage points lower than the general standard for government investments. Serious disturbances in the field of energy, unlike other areas, can lower GNP by a multiple, so some component of the energy investment can be regarded as an insurance premium whose purpose is to attenuate the economic impact of large disturbances in the world oil market.

Nordhaus (1994) undertakes a sensitivity analysis of his geo-economic policy optimizing model of climate change, allowing eight key parameters to take on different values, and calculating the impact on the model's endogenous variables, such as emissions, temperature increase, warming damage, world output, etc. He then re-calculates the optimal mitigation policy taking into account these uncertainties. Not surprisingly, mainly because of significant non-linearities in the model, the optimal reduction in greenhouse gas emissions, and the carbon tax required to achieve it, is higher in the presence of these uncertainties than it would be with confident best guess projections of the future. Concretely, the optimal carbon tax during the 1990s under the uncertain conditions postulated by Nordhaus is $12 a ton, compared with under $5 a ton on the best guess projection. Under uncertainty, of course, we may learn over time, so the optimal policy changes in response to new knowledge.[12]

What about the possibility of truly disastrous outcomes as a result of global warming? While the scientific community does not put a high probability on any of them, three are sometimes mentioned: 1) sufficient warming to release the extensive methane contained in the arctic perma-frost, leading to a strong and possible rapid reinforcement of warming; 2) sufficient warming to break up the antarctic ice dam and release great volumes of ice into the ocean, raising its level several meters rather than half a meter, and rapidly; or 3) glacial melting in Greenland of sufficient volume and character to deflect southward the warm north Atlantic currents, paradoxically making Europe a much <u>colder</u> place. These possibilities, however remote, raise the question of risk aversion and how much insurance societies are willing to buy against improbable but highly costly contingencies.

There is no doubt that individuals vary greatly in their degree of risk aversion, and that commercial insurance policies do only a modest job of bringing these diverse preferences into harmony at the margin. The market for differences in preference regarding risk is much less well developed than the market to take advantage of differences in time preference. Each society has its own mechanism, through the political process, for deciding and acting on the degree of collective risk aversion. But the mechanism for the world as a whole is even less well developed, being mediated through diplomatic conferences such as those at Rio in 1992 and Kyoto in 1997, followed by public debate and ratification.

The political process, while essential for making decisions on collective risk, contains some serious weaknesses, most notably that the discussion is not conducive to honesty and straight-forwardness. Some risk averse parties will naturally exaggerate the risks in order to persuade those who are less risk averse than themselves. Some risk averse parties will attempt to minimize the estimated costs of early action, or suggest that they can be borne by non-voters (e.g. corporations) in order to gain the support of voters less risk averse than themselves. And some parties will use legitimate concerns with the issue at hand, e.g. greenhouse warming, to encourage society as a whole to adopt a "life style" more congenial to them, e.g. by less reliance on the automobile, what for many has been a greatly liberating device. In these last cases, alarms over greenhouse warming become instrumental rather than the true objective. On the other side, those who expect to bear the costs of political decisions in response to concerns over climate change will tend to minimize the risks and exaggerate the costs of mitigation. In short, we should be on guard against strong but wrong or misleading or exaggerated arguments put by all sides to the case.

One way to deal with a potentially important problem which is subject to profound uncertainties is to establish a framework for action with broad participation and institutional procedures for integrating new information into decisions, as has been urged by Schmalensee (in Nordhaus, 1998), but to avoid bold early actions that may turn out later to be quite mistaken.

IV. International Burden Sharing

Suppose in light of all the evidence the international community, as represented by national governments, decides that steps should be taken to reduce greenhouse gas emissions and that, for reasons noted, it should involve many or all nations. What might be the substance of a treaty to restrain the emission of greenhouse gases? The first approach, reflected in the Kyoto Protocol, is to impose agreed national targets on emissions, possibly permitting some of the allowed emissions to be transferred from one state party to another, a feature that would significantly reduce the costs of a given reduction in emissions. A second approach that has received less emphasis would reach agreement on a set of actions that state parties would agree to undertake, with a view to reducing emissions. In my view, mutually agreed actions have better prospects of success than national targets, the approach adopted in the Kyoto Protocol.

National Targets. If targets are to be set, on what basis should they be set? When quantitative targets are imposed within countries they almost universally respect recent history, being allocated roughly in proportion to recent use (e.g. oil refinery runs or emission of sulfur or harvest of halibut). Targets based on emissions in a fixed base year such as 1990, as at Kyoto, have a similar character. They in effect allocate property rights to the existing tenants, accepting the right of ownership by virtue of possession or use. Targets allocated on this basis will be completely unacceptable, however, to countries that are or expect to be industrializing rapidly, with disproportionately rapid growth in demand for fossil fuels. They will argue that most of the existing stock of greenhouse gases generated by humans was emitted by today's rich countries, and that those countries should therefore bear a disproportionate responsibility for cutting back. Thus developing countries did not commit themselves to reduce emissions at Rio or Kyoto, and within Europe Spain and Greece have expressed similar reservations.

At the other extreme, some observers have suggested that simple distributive justice would require that emissions targets be based on population. Such an allocation would favor heavily populated poor countries such as China, India, Indonesia, Bangladesh, and Nigeria. To be meaningful in limiting climate change they would require drastic cutbacks in emissions by today's rich countries, implying radical reductions in living conditions there. Targets based on population would of course be insensitive to varying resource endowments (e.g. for hydro-electric power) and the fact that countries depend on vastly different fuel mixes as well as different levels of fuel consumption. Reductions in living standards could be mitigated, but not avoided, by sale of unused emission rights from poor to rich countries. Trading emission rights will be discussed further below. But the financial transfers involved if emission rights were based on population would be immense relative to foreign assistance today, far more than is likely to be politically tolerable. If carbon emissions were to take a plausible value of $100 a ton, for instance, the typical American family of four would have to pay $2200 a year to sustain its current (direct and indirect) average level of emissions of about 26 tons a year, 22 tons over its per capita allocation (roughly 6 billion tons of carbon emissions a year divided by a world population of roughly 6 billion people). Total US transfers to the rest of the world would amount to $130 billion a year, over ten times current US foreign aid expenditures. Moreover, the transfers in practice would be made to governments, despite the underlying moral rationale for basing targets on population, and many these days would question the desirability of transferring large sums to governments whose responsiveness to the needs of their own citizens has been indifferent or worse (think of contemporary Iraq or Burma).

A natural compromise has been suggested: base the national targets on GDP (or recent past emissions) initially, and gradually convert them to targets based on population over, say, 25 years, to avoid the wrenching impact on life styles in the rich countries and the implausibly large transfers to governments of developing countries. Here, however, we encounter some unpleasant arithmetic with respect to population-based emission rights. In 1995 India's per capita income (on a purchasing power basis) was about 5.2 percent that in the United States. Suppose that per capita income in India grows at 5 percent a year over the next 25 years, and per capita income in the United States grows at 1 percent a year (this is a plausible scenario, although in reality the gap in growth rates is not likely to be so wide). Under those assumptions, Indian per capita income 25 years later (in 2020) would still equal only 14 percent of per capita income in the United States, and consumption of energy would be many times higher in the United States than in India, even if the ratio were not so high as seven to one. Thus under national emission targets converging on population after 25 years either India would not be effectively constrained or the United States would be very tightly constrained or (under tradable emission permits) there would be huge transfers from the United States and to India. The sense of global community is not likely to be great enough by 2020 to sustain such large transfers -- it is not that great <u>within</u> the United States today -- and in any case such large transfers either to governments or directly to citizens, by fostering a rentier mentality, would probably not be desirable, as some of the highly oil-dependent countries have discovered.

Perhaps the most reasonable basis for allocating emission rights and the obligation to reduce emissions would be to calculate a "business-as-usual" trajectory of emissions for each country on the basis of recent history, development prospects, and past experience with the evolution of greenhouse gas emissions in relation to economic development. Then each country could be charged with reducing emissions by a uniform percentage, chosen in relation to some measure of global reduction requirements, relative to the assigned trajectory. But of course even if this principle of allocation of rights and responsibilities were accepted as reasonable, the debate would simply shift to the choice of trajectories for each country. Developing countries aspire to grow rapidly. South Korea and Taiwan have demonstrated that growth of over eight percent for three decades is possible. Most developing countries will set their aims similarly high, and insist on energy-consumption growth to support them. They will be reluctant to accept lower emission targets without assurance that the technology will be available to achieve their growth targets with the lower emissions. Who is to say they are wrong?

Implementation. Once national targets have been established, they must be translated into conditions that induce firms and households to change their consumption patterns away from activities that emit greenhouse gases. For large firms, e.g. generators of electricity, that could perhaps be done by fiat, that is by setting quantitative limits for each generating plant. But for most economic agents the only practical way to alter behavior is to create price disincentives, that is, to tax the activities that generate the emissions. As noted above, a treaty to inhibit greenhouse gas emissions differs fundamentally from one which requires governments to act in a particular way, or proscribes governments from acting in a particular way. In this respect a treaty on greenhouse gas emissions differs from most treaties, although it would be similar to other treaties governing pollution of various kinds, and those governing the harvesting of the biosphere, especially fish.

Every international agreement must address the question of compliance, to be discussed below, and the associated question of monitoring behavior to discover if it deviates from the treaty requirements. In principle, given the objective, all significant greenhouse gases should be covered. In practice, given the many actors involved and the many sources of emissions, such broad coverage would be impossible to monitor and police. For practical reasons, therefore, attention is usually focused on fossil fuel consumption (plus a few other concentrated emitting activities, such as cement production). Monitoring the consumption of fossil fuels is more or less manageable, since most of it must pass through some relatively narrow choke points, e.g. gas pipelines, oil refineries, electricity generating stations. Most coal production can be monitored at mine-head or on the barges and railroads that transport it.

But this still leaves out a lot of greenhouse gas emissions. Only about half of the greenhouse gas emissions (measured by radiative forcing, which is what is relevant for climate change) since 1850 came from the burning of fossil fuels.[13] Important contributions have also been made by changes in tropical land use (e.g. burning tropical forests), fuel wood, livestock and rice cultivation, town dumps, and gas pipeline losses. Omitting these sources from a regime based on national targets thus would represent a significant shortfall in coverage. The Kyoto Protocol covers 24 gases, including methane and nitrous oxide, in addition to carbon dioxide (see CEA (1998), p. 25 for a list, with the global warming potential of each gas). Monitoring emissions of all these gases will be difficult, and probably impossible if developing countries were covered by the requirement.

If the fossil fuel carbon emission targets for rich countries are demanding, how are they to be met? Conceptually, there are four ways: 1) greater efficiency at converting fossil fuels to usable energy in existing plant; 2) switching fuels from high to low carbon per unit of energy (basically, from coal to natural gas); 3) building new plant and machinery that uses less carbon per unit of usable energy (e.g. nuclear power plants); and 4) reducing end-user demand for energy. Unfortunately, there is little scope for further change at the easiest monitoring points. Obsolete generating plants can be replaced with more efficient or less carbon dependent ones, but replacement demand in the OECD will be modest over the next 20 years, and to replace faster than required by obsolescence becomes extremely expensive. In developing countries the demand for electric power is rising rapidly, by 300 percent between 1990 and 2010, versus 20 percent in OECD, so most of the 2010 generating capacity in those countries could in principle be designed to use low carbon-dependent technology.[14]

The consequence is that most of the reduction in the rich countries must come from downstream, at or near the points of final demand, where the number of consumers is greatest. Quantitative rationing is neither desirable nor feasible at this point in market economies, so the reductions must be achieved by some combination of price (dis)incentives and exhortation through publicity and education on best practice. Many consumers are not aware of the ways they can conserve energy without radical changes in life style. But in either case, as noted above, the key to success is not at the inter-governmental treaty level, but rather in the incentives each government can provide to its own citizens. A treaty merely provides a vehicle for rough "burden-sharing" across countries and some international discipline in pursuit of the targets.

The fact that the opportunities for reducing omissions in new electric generating plants and other new industrial facilities will be greater, and the marginal cost lower, in developing countries than in mature economies has led to emphasis on "joint implementation," a procedure whereby agents in rich countries can get credit against national targets in rich countries for emissions-reducing investments in developing countries. The idea is attractive. But under Kyoto the developing countries will not have national targets. Therefore avoiding reductions in emissions in rich countries by investing in poor countries by itself will not reduce global emissions, since much investment must and will be undertaken in developing countries anyway. Reducing global emissions can be accomplished only by establishing detailed criteria for "additionality" in emission-reducing new investments, that is, by establishing (constantly changing) norms by country by project for least cost power generating or energy-using investments, and counting reductions in emissions relative to such norms. Such a procedure would be a daunting task, both complicated and controversial, because it would necessarily involve both judgement and approximation.

Agreed Actions. There is an important alternative to setting national emission targets. That is to agree internationally on a set of actions, of course calibrated to achieve the desired emissions (ultimately, as stated at Rio, set to stabilize the atmospheric concentration of greenhouse gases, an objective that is too radical for specification in the near future, even as low as twice the 1800 level.). Since to accomplish their quantitative objectives governments must in any case create the appropriate behavior-altering incentives for their citizens, and since as we have seen setting a national allocation of global emission rights for both rich and poor countries is likely to prove so contentious as to be impossible, it may be far easier simply to agree on a common use of instruments. For problems such as reducing emissions, the favorite instrument of economists is to tax the offending activity. All countries would agree to impose a common carbon tax, which would increase the price of fossil fuels in proportion to their carbon content (with possible tax exemptions for uses that do not produce carbon dioxide, such as production of some plastics). Such a tax would have at least two major advantages. First, it would encourage reduction of emissions to take place where that can be done at least cost, since all emitters would have the same incentive to reduce emissions, but only those who saved more in tax payments than it cost to reduce emissions would undertake reductions; others would simply pay the tax. It would provide encouragement everywhere for fuel switching toward natural gas (with benefits accruing mainly to Russia and Iran, the countries with the largest known gas reserves) and more importantly to conserve generally on the use of fossil fuels.

Second, it would generate revenues for governments that have trouble finding sources of revenue that do not have negative effects on economic incentives to work, save, or undertake commercial risks. That should make it attractive to finance and economics ministries everywhere. Where the revenues are large, as they eventually would be, the new tax should be phased in gradually, and growth can be encouraged by reducing other taxes, e.g. those on foreign trade or on earned income. Taxes on fossil fuels would of course have some undesirable effects, such as delaying the switch from fuel wood to fossil fuels in poor countries. But it would be impractical in most cases to tax fuel wood.

In principle, it would be possible to extend the idea of a common carbon tax to methane as well, covering wetland rice production, decomposable refuse, gas pipeline losses, and cattle raising, but that more difficult step could perhaps wait until a later stage.

The imposition of a common carbon tax would be easy to monitor. Enforcement of the tax would be more difficult to monitor, but all important countries except Cuba and North Korea hold annual consultations with the International Monetary Fund on their macroeconomic policies, including the overall level and composition of their tax revenues. The IMF could by mutual agreement provide reports to the monitoring agent of the treaty governing greenhouse gas emissions. Such reports could if necessary be supplemented by international inspection both of the major tax payers (e.g. electric utilities) and the tax agencies of participating countries.

Imposition of taxes by international agreement imposes a major problem for democratic countries, however, since taxation goes to the heart of parliamentary prerogative, and most will not welcome taxation by international agreement, even with the requirement for parliamentary ratification.

Moreover, as 1993 experience in the United States with a btu-based energy tax illustrates, even modest energy taxes are at present politically unpopular. The European Commission proposed a somewhat more ambitious tax for energy, rising to the equivalent of about $10 a barrel (roughly 50 percent) of oil by 2000. That tax was never enacted. Moreover, the proposal paradoxically but not surprisingly gave special preference to coal (which is produced at high cost in a number of EU countries), the most carbon-intensive of the fossil fuels, and would also have levied a tax on nuclear power, the least carbon-intensive major source of energy.

Two additional possible problems need to be mentioned, neither insuperable. The first concerns the fact that energy (especially oil) is taxed differentially among countries in the mid 1990s, and some countries continue to price both coal and oil well below world levels. Should a uniform tax be levied on an uneven initial condition? If existing pricing practices are taken to reflect existing national preferences with respect to how best to use each country's authority over the allocation of resources, a case can be made that the new carbon tax should be uniform, not the total tax burden on fuels. Of course, national policies would have to be monitored to assure that the effect of the new tax was not undermined by other changes in tax or subsidy policy.[15] Alternatively, the treaty could simply require a minimum national tax on emissions from fossil fuels, allowing existing taxes to could toward that minimum, as advocated by Nordhaus.

The second possible problem concerns the disposition of revenue. Such estimates as we have suggest that to have a significant impact on emissions the tax might have to be substantial (more on this below). A substantial tax on a major input to modern economies would generate much revenue. To whom should it accrue? Oil-producers will suggest that if oil is to be taxed, they should levy it and get the revenue -- indeed, that is what OPEC's attempts to control oil prices amount to.[16] Oil-consuming countries, however, would feel doubly aggrieved if they must charge more for oil to discourage its consumption yet they do not get the revenue; they will insist that the tax be levied on consumption and accrue to them, not least so that they may reduce other taxes to assure their continued prosperity and growth. In practice, the latter view is likely to prevail.

There is, however, a third possible claimant for the revenue: the international community. The international community has accepted a number of collective obligations that are cumulatively expensive. Caring for refugees and peacekeeping are only the most apparent. Refugees alone cost the United Nations \$1.3 billion in 1995, and peacekeeping operations also cost around \$1.3 billion. Special assessments are now made for these activities, and several countries, including Russia and the United States, are in arrears. The regular UN budget runs at \$1.2 billion a year. In addition, donor countries finance UNDP and IDA (at about \$5 billion a year) for economic assistance to the poorest developing countries. The Rio Convention conditions cooperation by developing countries in reducing emissions on new financial support from the rich countries. Some or all of these activities could be financed in part from revenues from an internationally-agreed tax levied by all countries in pursuit of a common objective; obviously the major emitters, currently the rich countries, would pay most of the tax. But as poor countries develop, their contribution would increase automatically, an attractive feature of such an arrangement. These collective needs, while substantial, are nonetheless modest in terms of the total revenue likely to be available from an effective carbon tax.

Estimates from several global energy-environment models suggest that a uniform reduction in carbon emissions from a "business-as-usual" baseline for each country or region would require very different carbon tax rates if that were the policy instrument used to reduce emissions. That result suggests that a uniform tax rate across the regions studied would result in quite different reductions from the baseline -- as one would expect from the observation that countries around the world use energy with very different degrees of efficiency. Table 4 reports the carbon tax (in $1990 a ton) that would be required in five regions in the year 2050 to reduce carbon emissions by two percent per year from the baseline trajectory. Since the baseline trajectories project an increase in energy-related carbon emissions from roughly 6 billion tons a year in 1990 to 11 to 19 billion tons in 2050, the two percent a year reduction would leave emissions that ranged between 3.3 and 5.7 billion tons in 2050, i.e. below the levels of 1990.

Two points are noteworthy about Table 4. First, there are large differences among the columns (each reporting a different study), reflecting different assumptions about baseline trajectories, inter-energy and factor substitution possibilities, energy-saving technical change, and the presence or not of a non-carbon-emitting backstop source of energy. So at this stage there is little agreement on the costs of reducing emissions by an agreed amount.

Second, in each of the studies there are substantial variations in the required carbon tax across the rows, that is, from region to region, reflecting markedly different opportunities for reduction of carbon emissions. That suggests that global economic efficiency calls for diverse responses across regions, keyed to a common "shadow price" for emissions of carbon (full efficiency would impose analogous charges on production of methane -- e.g. from rice and cattle -- and other greenhouse gases, which are not included in the studies reported here). Countries that cut more would of course pay (collect) less tax.

By 2050 the world price (in 1990 dollars) of oil, 56 percent carbon by weight, is assumed to be $50 a barrel, two and half times its price in 1997; the price of coal, 75 percent carbon by weight, is assumed to be $60 a ton, about 50 percent above the recent price at points of importation. Thus a tax of $208 per ton of carbon in 2050 would represent a 31 percent tax on oil at that time, and a 260 percent tax on coal. The loss in GDP engendered by this emission reduction program ranges (across the studies) from 1.3 percent to 4.9 percent in 2050 for the United States, from 2.3 to 6.4 percent for the former Soviet Union, and from 2.1 to 5.1 percent for the rest of the world (today's developing countries, minus China) (Dean and Hoeller, 1993, p.157). These results must be regarded as merely exploratory rather than definitive, but even the low estimates suggest a substantial cost to bringing energy-related CO_2 emissions below 1990 levels. As noted above, permitting trades among regions -- a uniform carbon tax achieves a similar result -- would reduce these costs significantly, but would still leave them substantial.

The revenue these taxes would raise is also substantial. For instance, a $208 per ton carbon tax in the United States would raise nearly $300 billion in revenue, 1.8 percent of 2050 GDP. A $329 per ton carbon tax in the rest of the world would raise $610 billion in 2050, nearly 3.2 percent of rest-of-world GDP in that year.

Trading emission rights. A gain in efficiency of emission reduction similar to that achieved by a uniform world carbon tax can be achieved by allocating national targets to the major emitters of carbon dioxide, and allowing the emitters to purchase or sell emission "permits." A world market would quickly develop in such tradable emission permits, with a uniform world price. An emitter who could reduce emissions at a cost lower than the permit price would have an incentive to do so, and sell its unneeded permits into the world market. An emitter who could reduce emissions only at a cost above the permit price could save money by buying enough permits to cover its excess emissions. The figures in Table 4 suggest that there would be much scope and mutual gain from a global market in permits, since the estimated costs of reducing emissions vary greatly from region to region, in all the models.

The US government has estimated the gains from trading emission rights, adapting one of the leading economic models on energy use for the exercise. It estimates that the marginal cost for meeting the Kyoto target of 93 percent of 1990 emissions by 2012 would be about $200 a ton of carbon (calculated from CEA (1998), pp. 52-53). If emission permits were allocated and could be traded among Annex I countries, this cost would be reduced by 72 percent, to $56 a ton. Americans would not meet the seven percent reduction themselves, but rather would buy permits, mainly from Russians, who would have an easier time meeting their Kyoto target of no change from 1990 because of the collapse of heavy industry in Russian after 1990 and because of the considerable scope for improving the efficiency with which energy is used in Russia. Adding some key developing countries such as China and India to the trading regime would reduce the permit prices further, to an estimated $23 a ton, permitting Americans to buy more permits, more cheaply. The developing countries, by the same token, like Russia would receive substantial payments for their surplus emission rights. Indeed, as Bernstein et al.(1998) point out, any regime that in effect taxes fossil fuels, excludes some (non-Annex I) countries from the control regime, and does or does not allow trades in emission permits among the participants will in the long-term have substantial re-distributive effects among countries, in location of energy-intensive industries (to countries not covered by the regime), hence in trade and investment flows, and in terms of trade (especially away from exporters of fossil fuels), as well as through sales of emission permits.

A pre-condition for an effective market in emission rights is that well-defined property rights be conferred on the trading parties. These could in principle be governments, but in most countries these would have to be extended to the parties that actually do the emitting, e.g. electric generating firms, or produce the emitting products, such as oil refiners. That is, the national targets would have to be allocated to the relevant firms. Allocation of such emission rights would be a non-trivial political issue because of the distributional implications. As noted above, the historical tendency is to allocate quotas on the basis of historical performance. But the emission rights would have substantial value, and there would be little social merit, 50 years from now, to allowing the grandchildren of today's key emitters to continue to own the emission rights. The distortions over time from "grandfathering" the emission rights could be avoided by auctioning the rights from the start, with governments to get the revenues. They would use some of the revenues to subsidize temporarily today's emitters, who would have the major burden of adjustment to the new regime.

Because of the need to establish clear property rights to emissions before an efficient trading regime can function, such a regime can include only Annex I countries under Kyoto, since other countries have no emission targets. To include key developing countries would require their agreeing to (necessarily growing) national targets and to a mechanism for allocating national targets to the emitting firms. Such allocation would of course be a strong temptation to graft and corruption, since on current estimates such rights would have substantial value.

A permit trading regime would moreover require careful monitoring and enforcement, to ensure that parties that had sold emission rights actually cut their emissions to levels permitted by the permits they retained.

Another implication of a trading regime would be potentially large transfers of wealth from permit-buying countries to permit-selling countries, with the magnitude of the transfer depending not only on the price of the permits but on the initial allocation of emission targets, an issue already touched above.

Of course, implementation of the Kyoto targets, without extension or global trading, would also have distributional implications across countries, brought about both through the relocation of high energy-using activities to those countries without targets (and the associated investment), and through changes in the terms of trade that would occur as a result both of implementation of Kyoto and the secondary adjustments to that implementation.

The Australian Bureau of Agricultural and Resource Economics (ABARE, Commonwealth of Australia, 1995) has placed carbon-emission stabilization among Annex I countries into a general equilibrium framework involving a world economy of ten regions and 17 economic sectors -- a framework that permits rough estimation of the impact on GDP, location of production, terms of trade, and economic welfare in the designated regions. Under a scenario in which Annex I carbon emissions are stabilized at 1990 levels by 2000 (the report was published before Kyoto), but without joint implementation, global emissions decline 91 percent of the targetted reduction by 2020, the remaining nine percent having "leaked" to non-Annex I countries through the relocation of energy-intensive productive activities (the leakage rises to 13 percent under a 20 percent reduction target). The terms of trade of the major industrial countries (EU, USA, especially Japan) improve, due both to a fall in world oil and coal prices and to a cost-induced rise in prices of industrial exports; the terms of trade of other regions worsen by varying amounts, due to the same two factors. Economic welfare declines (by varying amounts, up to 1.7 percent) in nine of the ten regions, ASEAN (with a gain of 0.35 percent) being the exception. Because of changes in the terms of trade and mandated but regionally differentiated (energy) cost increases, changes in economic welfare can deviate substantially from changes in GDP.

The Kyoto Protocol, if taken seriously, will be costly to implement, with large impacts on society in most Annex I countries, but with little benefit to the climate. Signatory governments have not leveled with their publics on the full implications of implementing the agreement. When those implications are known, publics are likely to balk; a plausible forecast is that the ambitious targets of the Kyoto Protocol will not be met by 2012 in most Annex I countries. A cynic might argue that politicians understand this fully, and have undertaken a classic straddle to have their cake and eat it too: cater to the single-minded constituents demanding immediate action on climate change, while committing themselves to an international framework that is likely to prove unworkable, which will not be a tragedy since it may be neither necessary nor desirable.

V. Compliance

Inevitably when the question of international coordination of policies arises, it brings with it the question of what to do about free-riders or non-compliers. Parties are sovereign states, and there is no over-arching disciplinarian, as there is (in principle) within countries. This suggests the possible use of fines (contemplated within the European Union for violations of its fiscal Stability Pact) or economic sanctions. The issue has already arisen in connection with non-signatories and non-compliers with the Montreal and London protocols on reduction of CFC production and use. Exports of CFCs to such countries are to be prohibited after 1993, and imports of CFC-containing products are also prohibited. Decision on how to deal with the more complicated question of trade in products that used CFCs in their production (especially electronic products) was deferred. These trade provisions, along with the carrots of financial help and technology transfer, may have helped to induce many more developing countries to sign the amended Montreal Protocol in London in 1990 than had agreed to the 1987 Montreal Protocol. But the disciplinary actions do not go beyond CFCs to encompass more general trade.

It would be difficult to deny imports that were related to the emission of greenhouse gases without in effect prohibiting trade with the offending country, since CO_2-producing energy is required for virtually all production. Yet prohibiting trade could impose costs not only on the offending countries but also on their trading partners that might well exceed the likely costs of greenhouse warming. The advantages of one international regime would be sacrificed for another. Even if the threat worked, in the sense that countries were induced to comply with the emission objectives and the threat therefore did not have to be exercised, its existence might induce some important countries -- China comes to mind -- to reduce their dependence on trade as a matter of policy to avoid the possible cost of sanctions in the future, and that too would represent a cost of compliance.[17]

Chayes and Chayes (1995) have argued that neither in fact nor in theory need treaty law rely predominantly on sanctions, and indeed that in many cases they are counter-productive. They conclude that most actual or apparent deviations from treaty provisions arise from ambiguity and indeterminacy of treaty language, from limitations on the capacity of governments to carry out their undertakings, or from major changes in circumstance from those prevailing at the time of treaty ratification. Deliberate violation of treaties is rare, and when it occurs on important issues (e.g. the non-proliferation treaty) major participants exert extreme pressure outside the treaty for resumption of compliance, as can be noted with the violation of the Non-Proliferation Treaty by Iraq and the threatened withdrawal by North Korea.

The key factors in assurance of compliance is commitment to the treaty objectives by the signatories plus a high degree of transparency in their actions. Many regulatory agreements have the potential problem of "free riders;" countries are more likely to adhere to the provisions if other governments are seen to be adhering to the provisions, so a regular system for monitoring and reporting on the activities and actions covered by the treaty is very important.

These days the very legitimacy of many governments arises from their responsibility for international relations and their integration into the community of nations. "...modern states are bound in a tightly woven fabric of international agreements, organizations, and institutions that shape their relations with each other and penetrate deeply into their internal economics and politics. The integrity and reliability of this system are of overriding importance for most states, most of the time. [Even the largest and most powerful states] cannot achieve their principal purposes...without the help and cooperation of many other participants in the system, including entities that are not states at all. Smaller and poorer states are almost entirely dependent on the international economic and political system for nearly everything they need to maintain themselves as functioning societies." (Chayes and Chayes, 1995, pp. 26-27) External and increasingly domestic pressure will usually keep governments from deliberately flouting internationally agreed behavior. The need to engage publics in the reduction of greenhouse gas emissions, however, raises the issue of the capacity of governments to carry out their international commitments. Taxes are easier to monitor than quantitative emission targets.

VI. Incomplete Steps toward Mitigation

Even if an effective international agreement to abate greenhouse gas emissions cannot be put in place, there are useful things that individual countries, and the international community, can do. In other words, useful action need not be confined to putting in place and implementing an international agreement to reduce emissions.

In the first place, as the foregoing discussion has indicated in many places, our ignorance remains vast about the processes of climate change, the likely social and economic impacts of climate change, effective techniques for reducing emissions with minimal social disruption, and how most effectively to disseminate best-practice techniques. Knowledge can be advanced along a variety of fronts, and this can be accomplished through individual country action as well as through internationally-sponsored research.

Much of this activity is of course taking place today, especially on improved energy efficiency and alternatives to fossil fuels, but governments should ensure that no promising idea is languishing for lack of funding.

It should also be clear, however, that better knowledge will not resolve some key issues, especially those concerning inter-generational distributional decisions and collective aversion to risk (although research may clarify the nature of the risks). These inevitably must be resolved through public discussion and political negotiations.

In the second place, even in the absence of effective international agreement countries may sensibly take steps to reduce greenhouse gas emissions. This may be partly to set an example for other countries, as the Netherlands seems to be doing. But it can also be good national economic or social policy. Subsidies and tax advantages to the consumption of fossil fuels can be removed, so that non-fossil sources of energy, or conservation of energy, can compete on equal terms with coal and oil. Countries can encourage the more rapid diffusion of available best practice in energy use, through schools and public-awareness programs. There are countless examples in every society of out-dated techniques still in use. Sometimes this is for good economic reason, but often it is simply out of ignorance of superior alternatives or inertia in making improvements. Good public information and social pressure can help overcome both ignorance and inertia. Sometimes out-dated regulations need to be changed before current best practice techniques can be adopted, e.g. in building codes or public utility regulation (where allowable rates are often based on investment in new generating capacity, for example, but not on in investment in conservation of electricity). Governments can provide funding for experimentation in socially desirable new technologies, to hasten their development to stage of commercial viability. Finally, governments can, on their own, impose higher taxes on use of fossil fuels, devoting the revenues to reduction of other behavior-distorting taxes.

There are many reasons other than inhibiting global climate change for adopting some or all of these measures: reduction of air pollution, reduction of urban congestion, and enhancement of energy security (especially with respect to imported oil). Reduction of greenhouse gas emissions would be a bonus, although a conscious one.

In the third place, international lending institutions such as the World Bank and the regional development banks are in the business, inter alia, of financing infrastructure projects in developing countries, where most of the world's investment in infrastructure will take place in the coming decades. Once infrastructure is built, society adjusts to it and it has long-lasting effects. Thus careful attention should be paid now to the longer-run social and economic implications of infrastructure investments being undertaken in the near future. The World Bank and its regional cousins are especially well placed to do this, and to guide the nature of new infrastructure in light of these longer-run considerations. Such infrastructure especially includes electric power generation, power distribution, transport systems, and other major power-using activities. Attention to the extent and character of waste emissions, including greenhouse gases, should inform these investments, with special attention to available best practice even when it is not considered by the principal contract-bidding firms. Concretely, the World Bank and others should seek viable alternatives to coal-fired electricity generating plants, re-examining among other things the suitability of modern nuclear-power technology with respect to safety, cost, and waste disposal.

A sensitive issue arises when low- or non-emitting investments cost <u>more</u> than the least cost investment (taking into account initial investment, maintenance requirements, and life-time input requirements). Should the World Bank nonetheless insist on the investment that is more friendly to the environment? If so, who should pay for the incremental cost? It seems reasonable in general that the

World Bank should decline to finance infrastructure investments that are unnecessarily damaging to the environment over the life of the investment and its related successors, and that the borrowing country should pay fully for the incremental cost of any environmental benefits that accrue directly to the borrower country; but that the international community should pay most or all of the incremental cost (depending on the income level of the borrowing country) associated with greenhouse gas emissions, where the benefits will accrue to the world as a whole.

This general injunction of course leaves open important operational questions, such as how much incremental cost should be acceptable, and how the valuation of various non-market benefits should be weighed against one another (e.g. nuclear waste protection and disposal versus greenhouse gas emissions).

VII. Contingency Planning

Many adverse developments could occur as a result of global climate change. It is much more difficult -- today, impossible -- to forecast with confidence what will happen. Some analysts have projected benign effects from global warming, and easy adaptation to the adverse effects -- especially for those whose income is enough above subsistence to give them room for manoeuver. Thus for this among many reasons developing countries give higher priority to economic development than to averting climate change if the latter in any way inhibits development.

The great uncertainty about impacts, the prospect of serious gainers as well as losers, the high apparent cost of near-term actions to reduce emissions significantly, for benefits both more distant in time and more uncertain in magnitude, and the need for eventual wide participation by countries with substantially different initial circumstances and hence greatly different priorities -- all these factors make early action to stop growth of greenhouse gas emissions, much less to lower them, highly problematic.

Suppose the best guesses about climate change turn out to be too optimistic; or suppose that despite accurate forecasts the international community is unable to reach agreement on costly, effective mitigation actions; or suppose despite international agreement countries prove unable to implement the agreements. What then will the community of nations do if accumulating experience suggests the climate change is likely to be great and clearly adverse? This possibility suggests the need for some contingency planning to supplement research to develop cheap low-emitting sources of energy and ways to satisfy human wants with lower requirements for energy. Such contingency planning can take two broad paths.

The first concerns how best to adapt to more serious climate change. It means inter alia pushing ahead with both the basic science and applications of genetic engineering in many areas, especially agriculture, but also to provide potential substitutes for possible useful species that may be lost. That could be supplemented by a systematic program for collecting, cataloguing, and storing genetic material, mainly but not exclusively from plants, in the form of seed banks and DNA.

The second concerns how to slow further warming as rapidly as possible. One route involves sequestration and even withdrawal of greenhouse gases, mainly carbon dioxide, from the atmosphere on a scale at least equal to continuing emissions. That will involve good stack absorbers and storage depositories of carbon dioxide. But it also might involve mobilizing the biosphere. Rapidly growing trees could be planted on a massive scale, especially as climate change extends the areas that can support them, for example by dropping seeds by air. More unconventionally, barren portions of the oceans could be fertilized with the requisite minerals (thought mainly to be iron) so that microscopic carbon-loving plants can thrive.

A different approach would involve reducing the incidence of sunlight on the earth's surface, for example by placing reflecting surfaces in space or by increasing the albedo by altering cloud formation or by placing particulates in the atmosphere, e.g. through jet engine exhaust or by using cannons or rockets from the surface.[18]

Endnotes

1. The principal tool of analysis for global climate change is a large computer model (General Circulation Model, or GCM), of which there are several in use, that attempts to model the earth's past and future climate as a function of received radiation, the characteristics of the atmosphere (such as concentration of carbon dioxide), and the dynamics of climate formation. These computer-intensive models are much improved over a decade ago, but still are in the process of continual refinement and adjustment, and have not yet demostrated their capacity for accurate forecasts. See any recent issue of the Journal of Climate for new adjustments and new runs.

Recently the issue has been raised whether the United States, at present the largest national user of fossil fuels, is actually a net emitter of carbon dioxide, since US forests are also growing rapidly, and growing trees sequester carbon. See Fan et al. (1998).

2. Excellent summaries of the scientific consensus and uncertainties about global climate change can be found in IPCC (1996b) and in Wuebbles and Rosenberg in Rayner and Malone (1998, vol.2).

More recent work suggests that increased ice in Antarctica induced by a warmer climate (due to higher precipitation there), by withdrawing water from the oceans, would reduce this projected rise in sea level somewhat, possibly by as much as fifty percent. See Thompson and Pollard (1997).

3. The European Union is treated as a single unit, with the maximum target reduction of 8 percent below emissions levels of 1990. The USA agreed to a reduction of seven percent, Japan to six percent, and Russia not to exceed the 1990 level.

4. This paper draws selectively on Cooper (1994), Cooper (1998), and Cooper in Nordhaus (1998).

5. In experimental settings a doubling of carbon dioxide increases yields of some C3 crops, including wheat, rice, and potatoes, by 30 percent; and C4 crops, including corn and sugar cane, by 7 percent. See Reilly in Nordhaus (1998), p.254.

Fischer and Rosenzweig (in Nakicenovic, 1996) also find that global warming will increase global food production by 2050, with CO_2-fertilzation playing an especially important role.

6. See any recent issue of the Journal of Coastal Research for evidence of extensive research on both human and natural changes in coastal areas and for human responses to the changes.

7. The estimated costs of climate change have generally declined from those offered in the early 1990s. See Mendelsohn and the discussion by Tol, Reilly, and Cline in Nordhaus (1998).

8. Private communication from Fred Singer.

9. As with cost-benefit analysis, those who argue against the need for a discount rate, e.g. Cowen and Parfit (1992), are simply making a mistake; a discount rate of zero leads to the nonsensical conclusion that the current generation should invest all its income above that required for subsistence so long as the net return on investment is positive, however small -- a result that both defies common sense and makes no moral sense.

10. See Nordhaus (1994) or IPCC (1996a), chapter 4, for an explanation.

11. See Cline in Nordhaus (1998) for both clarification and defense of the stance taken in chapter 4 of IPCC (1996a).

12. Nordhaus (1994) calculates an optimal policy for mitigation of climate change that calls for relatively modest mitigation and therefore much adaptation. Hence his carbon taxes are much lower than those designed to achieve more severe reductions in carbon emissions, such as those called for by the Kyoto Protocol.

13. Calculated from data provided in IPCC, 1996b, pp.18-22.

14. On one estimate, two-thirds of all new electric generating capacity will be installed in developing countries between 1995 and 2010 (CEA, 1998, p.33).

15. Anderson in Anderson and Blackhurst (1992) points out that simply removing the subsidies and price controls that now exist for use of coal in many countries would simultaneously increase trade and improve air quality -- as well as reducing greenhouse gas emissions -- by raising the world price of coal.

16. Indeed, the Rio Convention enjoins its Parties to "take into consideration" in implementing their policies the adverse effects on developing countries that are highly dependent on production and export of fossil fuels, among others (Art.4.10).

17 Threats to reduce trade and aid are of course used today to influence the behavior of countries, most notably in the area of development of nuclear weapons and other weapons of mass destruction (and, to some extent, missiles to deliver them). The day may come when greenhouse warming is widely agreed to be on a par as a threat to humanity with proliferation of nuclear weapons, but that is not yet the case.

18 A study by the National Research Council (1991) suggested that placing reflectors in space would be very costly compared with alternative ways to reduce the incidence of sunlight, but relative costs might be very different in three or four decades.

Table 1. Percentage Changes in Global Supply and Production of Cereals by Climate-Change Scenario

	Supply		Production	
World	No adaptation	Land use fixed	Land use fixed	No restrictions
GISS	-22.6	-2.4	0.2	0.9
GFDL	-23.5	-4.4	-0.6	0.3
UKMO	-29.3	-6.4	-0.2	1.2
OSU	-18.6	-3.9	-0.5	0.2

Note: Changes in supply represent the additional quantities firms would be willing to sell at 1990 prices under the alternative climate. Changes in production represent changes in equilibrium quantities, under new equilibrium prices. The results are based on $2xCO_2$ equilibrium scenarios for four climate models, those developed at the Oregon State University (OSU), Geophysical Fluids Dynamics Laboratory (GFDL), Goddard Institute of Space Studies (GISS), and United Kingdom Meteorological Office (UKMO).

Source: Darwin and others, 1995.

Table 2. Market Impacts (percent of GDP), 2.5^o C Warming.[a]

Region	Fankhauser	Mendelsohn	Tol
OECD	0.77	-0.17	0.27
Non-OECD	0.67	0.03	0.76
World	0.72	-0.18	0.52

a. Mendelsohn assumes a 2.5^o C rise in global mean temperature to take place in 2060, whereas Fankhauser and Tol assume this to happen in 2050. Note that only Tol has damage depending on the rate of climate change. In all three cases, vulnerability is assumed as in 1990.

Source: Tol in Nordhaus (1998).

Table 3. Selected Estimates of Global Marginal Abatement Benefit and Global CO_2 Marginal Abatement Cost ($US per ton C)

Benefit Study	Marginal Benefit[1]	Cost Model[2]	Marginal Cost	
			Stabilization	20% Reduction
Ayres & Walter	$30-$35	Jorgenson-Wilcoxen	$20	$50
Nordhaus	$7	Edmonds-Reilly	$70	$160
Cline	$8-$154	Manne-Richels	$110	$240
Peck & Teisberg	$12-$14	Martin-Burniaux	$80	$170
Fankhauser	$23	Rutherford	$150	$260
Maddison	$8	Cohan-Scheraga	$120	$330

1 For most studies, the marginal benefit increases over time. The estimates presented here correspond to the period 2001-2010.

2 Cost estimates are from a study by the Energy Model Forum of Stanford University, which ran 14 different cost models using common assumptions and standardizing for the emission reduction scenarios shown above.

Sources: IPCC (1996), Tables 6.11 and 9.4 .

Table 4: Tax Required by 2050 to Achieve a Two Percent per Year Reduction in Carbon Emissions from Baseline ($1990 per ton of carbon)

Model Region	Edmonds/ Reilly	Manne/ Richels	Green	Carbon Rights Trade Mod
USA	1096	208	340	754
Other OECD	734	208	299	365
FSU	325	990	180	2245
China	341	240	67	1109
ROW	1012	727	329	763

Source: Dean and Hoeller, 1993, p.153.

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