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Economic instruments and the greenhouse effect

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Economic Instruments and the Greenhouse Effect

SUMMARY

1) The recent build-up of "greenhouse gases" in the atmosphere means that there is a significant probability of global warming over the coming half-century. This prediction is subject to very great uncertainties concerning both the actual likelihood of warming, its possible magnitude, and the probable effects on the world economy.

2) Faced with these uncertainties, the nations of the world can be expected to adopt some form of minimum-regret response. At this stage, such a response is likely to consist of two elements: an accelerated programme of scientific research, and further steps towards the negotiation of international agreements to deal with the identified problems.

3) The 1987 Montreal Protocol on CFCs and halons has demonstrated the speed with which such agreements can be reached, and the possibility of their effective implementation, once political will is established. The 1988 Toronto conference resolution on first steps towards reducing CO_2 emissions over the long run opens the way to debate and negotiation over an international policy regime to tackle CO_2, methane, and nitrous oxide emissions.

4) We suggest that the key criteria to be met by any international anti-greenhouse policy regime are the following:

> (1) The regime should recognise the importance of encouraging appropriate sinks as well as restricting sources for the targeted pollutants.
>
> (2) The regime must be effective in reducing emissions of specified pollutants to some target path through time.
>
> (3) The targets, and the list of specified pollutants, should be able to be amended or adjusted continually as new information becomes available.
>
> (4) Monitoring and enforcement costs should be as low as possible, and should be borne (as far as possible) in the first instance directly by two groups: those responsible for the pollution, and those with a direct stake in enforcement of the regime. (The latter group should be able to anticipate recovering their costs from the polluters, so that in the final analysis the polluter-pays principle would apply.)

(5) The implementation of the regime should at least not subvert, and at best should contribute towards, the development of poor countries .

(6) The regime should be able to take account of the different positions of specific countries and industries.

(7) The regime should make resources available to promote technology transfer - both the promotion of energy-saving technologies in general, and the installation of those technologies in less developed countries.

5) This paper considers four policy options which show promise in the search for a long-run solution to a perceived greenhouse threat. These should be regarded as potentially-complementary, not mutually-exclusive, elements in a total policy package. The options are:

(a) a system of tradeable emission permits or entitlements, issued by an international agency and exchanged through an open international marketplace;
(b) a system of detailed quantitative emission permits enforceable in international law;
(c) a system of taxes or levies targeted at emissions or at consumption of specified fuels;
(d) a convention setting ambient standards to be met on a country-by-country basis, and legitimating international sanctions against offending countries.

6) The tradeable-permit option has very great attractions in an international setting. It promises flexibility, incentive-compatibility, a potential contribution to global equity, and the advantages of an impersonal mechanism for secondary allocation of emissions using a clear-cut international price mechanism. It is also in tune with the evolution of contemporary thinking on pollution control. The two main problems are likely to be first the amount of political and institutional innovation required (the scheme would be appropriate in the context of bold thinking and ambitious targets, but could degenerate to bureaucratic tinkering if tailored to a cautious defence of the status quo); and second the real difficulty of designing a scheme which rewards investments in greenhouse sinks while remaining transparent and simple in operation. Because permits would be targeted at sources, simplicity would dictate that the quantity issued be governed by <u>gross</u> global emission targets; but the overall aim of policy should be a focus on <u>net</u> changes in gas concentrations. A possible compromise would be to apply a levy on all transactions in the market for permits, in order to finance incentives for sink creation.

7) The second approach, holding individual polluters accountable for their adherence to internationally-set and policed restrictions, points to measures which show some promise as <u>part</u> of an international convention. But any full-blown attempt at detailed international regulation of individual economic agents faces near-insuperable problems. Quite apart from the large inroads

on national sovereignty which would be implied, such a scheme would be likely to prove undesirably rigid, and unlikely adequately to address global equity issues. There would also be a severe risk of giving windfall rents (i.e. perverse incentives) to polluters. The best that can be hoped for here is probably a treaty giving citizens of any country standing to sue polluters in the courts of the polluters' own countries on grounds of damage to the global commons.

8) "Carbon taxes" and similar devices are difficult to harmonise internationally, and are open to manipulation by individual nations' exchange-rate policies. In general such measures work best when applied by national governments in pursuit of national objectives; in the international arena, there is no institution with the power to tax citizens or sectors within sovereign nations. Individual governments might well be encouraged to develop their own anti-pollution policies by means of such devices, especially where such policies are designed to make a country a leader of world action (as is the case with, for example, Sweden's carbon tax). But taxes do not represent an effective instrument for pursuit of initiatives at the international level.

9) An international convention binding participating countries to meet certain ambient standards is the most obviously feasible first step in confronting the greenhouse problem. The two major advantages are first, the limited loss of sovereignty involved (since each government would be free to design its own policies to reach the standards) and second, the use of territory-by-territory monitoring which would automatically reflect net, rather than gross, contributions by each country to the overall problem. Major issues of accountability and enforcement would have to be resolved, and credible sanctions would have to be at least contemplated to bring offenders into line. International sanctions on trade and financial flows, however, have limited long-term credibility and undesirable side effects on the working of the world economy. A tradeable-permit system, of the type discussed above, could provide a natural and efficient means of administering such a convention, provided individual governments were prepared to enforce on their own polluters the requirement to purchase internationally-issued emission permits.

10) The discussion in this paper tries to avoid the distinction between "market instruments" and "regulation" that has structured much recent debate on anti-pollution policy, especially in the OECD. This is because neither approach on its own offers a fully-satisfactory policy regime. The aim in designing an international agreement should be to assemble a package of measures which are effective and mutually supportive. Our discussion of "economic instruments" therefore ranges across a wider field than just narrowly-defined market mechanisms.

I. A STATEMENT OF THE PROBLEM.

(I.1) Human activity is changing the composition of the Earth's atmosphere by discharging into it larger volumes of certain gases than the biosphere is capable of absorbing. Changing atmospheric composition implies some change in the equilibrium temperature at which the atmosphere maintains the terrestrial greenhouse. For the immediate future, the expected change is upwards by a few degrees, but there is still great uncertainty about what this implies (a) for the Earth as a whole, and (b) for individual nations.

(I.2) At this stage of scientific research, uncertainty surrounds all predictions of future temperature changes, weather patterns, and sea-level changes (Mahlman 1989, White 1989, Schneider and Rosenberg 1989). Observations of the rising trend of greenhouse gas concentrations are clear-cut, and knowledge of the origins and sinks for these gases is expanding rapidly. Predictions of the effects on climate, however, rest heavily on computer simulation models and on interpretation of the geological record. Typical statements in recent surveys by scientists are

> "... so many ... factors are involved that it is an open question as to whether we are beginning to see 'greenhouse' climate changes emerge" (Tucker 1989, p.3)

> "... neither the precise magnitude nor the global distribution of a change can be accurately predicted..." (Bolin 1989 p.1)

> "In my view, the jury is out. We are confronted wiith an inverted pyramid of knowledge: a huge and growing mass of proposals for policy action is based upon a handful of real facts... Projections based upon mathematical approximations of atmospheric and oceanic conditions are credible but uncertain. Evidence from the climatic data is equivocal..." (White 1989 p.11).

(I.3) In previous geological eras, the terrestrial biosphere has succeeded in absorbing and fixing high atmospheric concentrations of carbon, but the process has been very slow by the human time scale - tens or hundreds of millions of years - and has been accompanied by striking changes in climate and surviving species. The outlook if present trends continue, therefore, is that at some unpredictable stage of atmospheric restructuring there could be rather large effects which will impact on the ability of the human race to continue as a fossil-fuel-using species.

(I.4) Given the uncertainty over exactly what consequences will flow from the undoubted rise in greenhouse gas concentrations, a risk-avoiding strategy by the global human community would aim to expand knowledge as rapidly as possible, while seeking to slow or stop the change in atmospheric composition, thus reducing or removing the <u>risk</u> of catastrophic climate changes. (On the economics of catastrophic risk cf Collard 1989.)

(I.5) Neither an adequate research effort, nor effective worldwide pollution abatement, can be expected to result from the operation of market mechanisms on their own. Research results and clean air are public goods; for individual nations and their citizens at each moment of time there are strong incentives to free-ride on the efforts of others, and few immediate benefits to be secured from going it alone. The effects of one country's pollution, or pollution-abatement efforts, are not captured by that country alone because the global ecosystem takes no account of national boundaries. There are therefore potential benefits for all from international policy cooperation.

The appropriate model from game theory is the indefinitely-repeated prisoner's dilemma, which is known to favour, but not to guarantee, the emergence of cooperative solutions from the strategic behaviour of rational participants (Axelrod 1984; Sugden 1986; Ordeshook 1986 Chapter 10).

(I.6) Even in a situation where large countries such as the USA , UK and France appear disposed to take an active leadership role, policy interventions are most likely to be effective if pursued on a multilateral basis. Most literature on anti-pollution policy instruments, however, has focussed on the design of national or regional, not global, policy design. This is particularly true of the existing literature on the use of economic instruments (e.g. OECD 1989). In the preparation of this paper we did not locate any systematic treatment of international economic instruments, even though the issues are substantially different from those faced by national policymakers because of the intervention of national sovereignty as a constraint upon moves towards world government.

(I.7) Some relevant figures on the orders of magnitude involved in the greenhouse process are reproduced in Appendix 1. The priorities for action in the immediate future seem fairly clear (UNEP and Beijer Institute 1989; Darmstadter and Edmonds 1989; Bolin 1989; Jackson 1989). Elimination of CFCs, and measures which shift the world energy and industrial systems away from fossil fuels (or at least cut down the share of coal and oil) come top of the list. Forest preservation and reforestation to set back the greenhouse timetable, together with changes in the agricultural practices which generate methane and nitrous oxide emissions, come next. Reduction in methane leakages from natural gas and coal fields, and measures to remove ("sequester") CO_2 from the atmosphere by long-term biological or mechanical means, also figure in the current proposals. The discussion in this paper will focus mainly on fossil fuel emissions, since the question of CFCs and related ozone-depleting gases is already being tackled, so that fossil-fuel use and deforestation represent the next immediate agenda items for international consideration.

(I.8) The atmospheric-composition problem can be tackled from two sides: sources and sinks. Greenhouse gases have many sources, but the key marginal addition to pre-existing sources has been fossil-fuel mining and burning, while the main reduction in pre-existing sinks has come from deforestation. Reducing the rate of fossil fuel exploitation, thus, provides one leg of a long-run strategy. The other leg focusses on sinks - on increasing the biosphere's capacity to absorb and fix greenhouse gases, and on expanding the scale of artificial sinks, both temporary and permanent.

(I.9) The character and effectiveness of sinks varies widely. Only some of the sinks in the biosphere result in the fixing of carbon and other greenhouse-gas elements back into long-term inert or isolated forms. (Formation of carbonaceous rock on the ocean floor is an example of long-term fixing.) Most of the sinks in the biosphere, however, are short-run repositories of carbon and other elements during a stage of the cycle through which they move in nature. Trees, for example, fix carbon only for the lifetime of the tree; thereafter, the carbon is returned to the atmosphere by decay or burning, unless the tree is physically isolated from the natural cycle (for example, by becoming locked into fossil deposits where its carbon may remain for millions of years)(Trexler, Faeth and Kramer 1989).

(I.10) Over some range, the biosphere has the ability to increase its fixing activity, holding down atmospheric concentration of CO_2, for example, by raising the pace of carbon sequestration, and possibly by extending the phase of the cycle during which carbon is held out of atmospheric circulation - e.g. by more, or longer-lived, trees. Beyond that range, however, unless some new natural or human agency undertakes the task of fixing large amounts of carbon out of the atmosphere in inert form - e.g. by scrubbing flue emissions and burying the resulting large tonnages of solid carbon underground or on ocean floors - the outlook must be a cumulative long-term build-up in the atmosphere so long as fossil-fuel use continues on a large scale. By substituting wood for fossil fuels, a major expansion of world forestry could be part of a sustainable long-run solution to the problem (Sedjo and Solomon 1989 p.117).

(I.11) Because of the uncertainties involved in predicting the timing, scale, and nature of those effects, the greenhouse-gas issue is more difficult for economists to analyse than the familiar problem of the depletion of fossil fuel resources. If greenhouse-gas concentrations were expected to remain within tolerable limits up to the point where all existing reserves of fossil fuels are used up, then the long-run constraint within which humanity would have to operate would be merely that posed by resource depletion - namely, that human energy consumption must ultimately be constrained by the availability of renewable energy sources using "backstop" technologies. If, however, the greenhouse constraint binds before the resource-depletion one does, this shortens the timescale within which the transition to renewable, non-fossil energy sources will have to be accomplished.

(I.12) While there exist market mechanisms which (in economic theory at least) are expected to cope with the long-run problem of fossil-fuel depletion, there are no such self-starting automatic mechanisms to deal with global warming. Depletion of a marketed resource such as coal or oil, in theory, causes the price of the resource to rise over time as remaining stocks fall, with the price eventually tending to infinity as exhaustion is completed. (This is known as the Hotelling principle.) This rising price then provides the incentive for users of the resource to economise on its use, eventually turning completely to substitutes. Over very long timescales, this must imply substitution of renewable energy for depletable energy sources, provided the economic system survives.

(I.13) In the case of the greenhouse problem, the relevant resource - an atmosphere approximating to the gaseous composition under which the present ecosystem (including ourselves) has evolved - is a non-marketed public good. There is therefore no built-in mechanism to give expression to the need to economise on depletion of this resource (where "depletion" is understood in the sense of moving the atmosphere's composition away from some initial benchmark). The emergence of the greenhouse problem indicates that in the past, energy resources have not been priced according to any such optimal, Hotelling-type formula, adjusted for atmospheric externalities from fossil-fuel use. The absence of such an optimal pricing mechanism has led to an excessively high usage rate, which has the effect of shortening the time now available for a transition to renewables, and to inadequate incentives to induce energy-users to switch to or develop renewable backstop technologies.

(I.14) In designing artificial market mechanisms to deal with environmental issues, it is important to bear in mind the importance of imposing long-run sustainability as a constraint within which economic optimisation must take place. If this constraint is not imposed, as a decision taken by the present generation to restrict its own resource-using practices, then well-known problems arising from the logic of discounting will tend to lead to resource-use decisions which are non-optimal, in the very long-run sense that the present generation may "rationally" act in ways which eliminate future generations by steering the economic system to extinction. (Page 1977, Pearce 1976). Alternative theoretical approaches using multiple rates of time preference (Porter 1982) lack the operational bite of sustainability rules applied through quantity regulation (Pearce 1988).

(I.15) If the "global community" wishes to sustain the benchmark atmosphere composition, or a composition diverging from the benchmark at a limited rate, it will need to establish a system approximating the working of a market, or making up in other ways for its absence. In presuming the existence of sufficient political will to reach such an agreement, and to enforce global interests even when this involves some limited surrender of national sovereignty, the present paper glosses over key issues of the transition to a new order. The purpose here is to set out the sort of global measures which might emerge as parts of a negotiated policy to stabilise atmospheric composition.

(I.16) The speed with which international action against CFCs and halons has taken effect demonstrates the possibility of developing enforceable, or at least workable, agreements on a world scale. The approach taken to ozone depletion, beginning with a general convention (the Vienna Convention) and then adding detailed protocols as information improved and political will developed, points to the likely sequence of events for greenhouse gases in general. The 1988 Toronto resolution on CO_2 emissions means that some detailed commitments are already in sight. The issues with greenhouse gases, however, are much larger, more diffuse, and more complex than is the case with ozone-depleting substances. The latter are few in number, clearly identifiable, and traceable to a small number of producers. Consumer boycotts of non-safe aerosols provide an immediate, credible incentive for producers to switch to non-depleting alternatives; and the large chemical companies have been happy to make the switch, since backstop technologies are available, and windfall rents can be secured by reducing the supply of CFCs in markets where not all users are able to change-over in the short run.

(I.17) Greenhouse gases (GHGs) on the other hand, derive from a very wide variety of sources only some of which can be individually identified. Sinks are even more difficult to detect. Policies are therefore harder to target accurately. At the same time, backstop technologies to enable the world to switch over to non-fossil-fuel energy are not yet in sight on a sufficient scale to permit an immediate halt to net increases in atmospheric concentrations of GHGs. Even in the longer run, the nature of backstop technologies cannot yet be predicted with any certainty. Wind, solar, tidal, wave and hydro power all have a place in a renewable energy system, but none yet promises independence of fossil fuels.

(I.18) Nuclear power is more problematic, both because of unsolved problems of long-term waste disposal, and because the production (and ultimate reprocessing) of nuclear fuels involves large GHG emissions, regardless of the energy technology used. Mortimer (1989) estimates that a nuclear electrical generating system obtaining fuel from uranium ores of less than 100 p.p.m. would involve CO_2 emissions equal to comparable fossil-fuel generation systems. Known deposits of higher-grade uranium ore would suffice only to produce 10% of world electricity consumption for 150 years.

(I.19) A crucial component in any long-term solution to the greenhouse problem must be the widespread adoption of energy-conserving technologies, which would directly reduce emissions by cutting the energy demand associated with any level of global income. Technically-feasible savings amounting to half or more of current energy consumption are quite readily identified (Goldemberg et al 1987; Jackson 1989 p.8), but many of these technologies will become economically attractive only gradually as research and development lowers their cost and energy prices rise. Any successful policy regime which reduced emission levels, and allowed markets to transmit the resulting incentives to conserve energy, will open the way to substantial reductions in the world economy's energy to GDP ratio. In turn, this would permit considerable growth in world income without raising emission levels from those prevailing in the early 1980s (Darmstadter and Edmonds 1989).

II. GUIDELINES FOR INTERNATIONAL POLICY DESIGN

(II.1) The starting-point of any atmospheric policy regime would necessarily be an agreed set of quantitative targets, specified in terms of the concentrations of particular gases in the atmosphere to be achieved at each point in time over the period of the agreement. Working back from these target stocks of atmospheric gases, it would then be possible to prepare tentative upper limits on the permissible annual flows of emissions of these gases. Such limits would be tentative because of the uncertainties which exist over the changing levels of global sink capacity. Optimistically, sink capacity might turn out larger than expected, which would make the stock targets attainable with greater-than-expected emissions (or alternatively, enable lower stock targets to be reached with the given emissions level). Pessimistically, if the stocks of gases continue to rise for some time to come, as seems likely, the possibility arises of a degradation of sink capacity, which might require unanticipated tightening of emission limits.

(II.2) The structure of the problem - trying to control atmospheric stocks in an environment where sink capacity is unpredictable but almost certainly lower than current emission levels - leads inexorably to the conclusion that the centrepiece of any meaningful policy regime would have to be an enforceable upper limit on emissions, imposed through a system which is flexible enough to adapt to changes in that limit as new information becomes available through time. Flexibility and efficiency of application are advantages often claimed for so-called "economic instruments" which harness the price mechanism in the service of environmental regulation (Bohm and Russell 1985; OECD 1989), but it is important not to suppose that markets on their own can provide a means of defining or achieving sustainable emission limits. The price mechanism can be an efficient servant of emission policies once these are known, but it cannot be a substitute for such policies.

(II.3) We suggest that the key criteria to be met by any international anti-greenhouse policy regime are the following:

(1) The regime should recognise the importance of encouraging appropriate sinks as well as restricting sources for the targeted pollutants.

(2) The regime must be effective in reducing emissions of specified pollutants to some target path through time.

(3) The targets, and the list of specified pollutants, should be able to be amended or adjusted continually as new information becomes available.

(4) Monitoring and enforcement costs should be as low as possible, and should be borne

(as far as possible) in the first instance directly by two groups: those responsible for the pollution, and those with a direct stake in enforcement of the regime. (The latter group should be able to anticipate recovering their costs from the polluters, so that in the final analysis the polluter-pays principle would apply.)

(5) The implementation of the regime should at least not subvert, and at best should contribute towards, the development of poor countries .

(6) The regime should be able to take account of the different positions of specific countries and industries.

(7) The regime should make resources available to promote technology transfer - both the promotion of energy-saving technologies in general, and the installation of those technologies in less developed countries.

III. FOUR POLICY OPTIONS OUTLINED

(III.1) In this section we take it for granted that some mechanism has been agreed upon for setting global emission limits, or at least target ambient standards for the atmosphere. Our concern is with the instruments, and institutional arrangements, which might enable such targets to be applied and enforced. The following appear to be the main options open :

(i) **Impersonal market mechanisms for allocating the right to emit greenhouse gases** could be established which obliged individual polluters to pay a price for their emissions, and which drove that price to whatever level was required to achieve the rationed level of global emissions. This would require some new property rights to be created and allocated, and a legal basis for their enforcement agreed to by all nations.

(ii) **Direct legal restrictions on individual emission sources** could be used, under a system which established uniform emission standards across countries and which specified significant penalties for any breach of the regulations. Such a system would be based upon the concept of "damage to the global commons", and might be structured to give any individual or organization legal standing to sue an offending polluter, either in the courts of the polluter's own country, or in some international environmental court to be established by the treaty.

(iii) **Pigovian taxes ("carbon taxes")** could be imposed on polluters, at rates believed sufficient to reduce global emissions within the target levels. Such taxes would have to be collected by some agency - either an international body, or the participating national governments - and the disposal of the revenues would then be by institutional decisions at that level. Some indexing mechanism would be needed to ensure that exchange-rate changes did not result in severe cross-country distortions in the true incidence of the tax, and a registration system would be needed to identify emitting agents; this administrative and enforcement infrastructure would need to be financed, presumably from the proceeds of the tax. Taxes could be targeted either directly at emissions, or (easier to enforce) as levies on the production or consumption of specified fossil fuels.

(iv) **Governments could be made accountable for their territorial net emissions, or territorial ambient standards, with accountability enforced if necessary by a regime of international trade and financial sanctions.** Such a regime would leave to each individual national government the decision on how to limit emissions within its jurisdiction, but would provide strong incentives for them to do so by holding each state liable for excess global pollution costs generated in the process of producing its Gross Domestic Product (including, of course, its export production). To be credible, such a scheme would have to be able to threaten effective sanctions against any offending nation, up to and including the USA or USSR, without in the process completely disrupting the world economy. Because of the familiar problems with sanctions, there would in practice be heavy emphasis on consensus-building and moral suasion to bring nations into line. A central requirement would be a strong and incorruptible international agency with an unimpeachable reputation for fairness in its allocation of country emission quotas, or setting of country-by-country ambient standards, and with the moral authority to face down recalcitrant national authorities. Sanctions, if agreed, would be available to be used against the trade and investment activity of any country identified as exceeding an agreed quota of (gross or net) emissions, or guilty of failing to achieve agreed ambient standards. This would effectively be an extension of existing anti-dumping arrangements.

(III.2) All four regimes have precedents of a sort in recent history and in international law. The sections which follow look in more detail at the design and operation of hypothetical systems under each heading. The discussion will focus on the following issues:
- feasibility of designing an effective policy regime
- simplicity of the scheme in operation
- extent of encroachment on national sovereignty (and hence acceptability to national states)
- degree of conflict with existing legal and economic frameworks
- redistributive consequences.

(III.3) The goal should be to identify a regime which is effective, simple, self-enforcing, politically acceptable, progressive if anything in its impact on world income distribution, and which requires the minimum of overarching international authority. Of the four regimes considered, the first comes closest to meeting these criteria, but would be impossible to operate without the sort of international convention outlined in III.1(iv) above, under which governments would accept responsibility for ensuring that international standards applied domestically. A combination of (i) and (iv), thus, could provide the mainstay of a global policy. Elements of (ii) could usefully be included, and individual governments would remain free to use (iii) domestically as they saw fit.

(III.4) The four sections which follow consider the four identified options in turn.

IV. A MARKET-CREATING APPROACH: TRADEABLE ENTITLEMENTS

(IV.1) The regime to be outlined here is in effect a combination of existing US systems of "tradeable emission permits" and the OECD's "polluter pays principle", but is designed to operate on an international scale. Experience with tradeable permits has to date been restricted to national or sub-national political units, where results have been patchy (Hahn 1989; Tietenberg, 1985). Most recent theoretical discussion of tradeable-permit systems has also been confined to national or EEC-wide schemes (e.g. Bohm and Russell 1985; Stavins et al 1988; OECD 1989; Opschoor and Vos 1989; Tietenberg 1988 Chapters 14-16). Such instruments, however, seem ideally suited to the international arena for dealing with large-scale emissions of near-homogeneous pollutant gases.

(IV.2) The key institution required would be an international agency recognised as the sole legitimate issuer of global emission entitlements, acting on the basis of an agreed global budget for gross greenhouse gas emissisons, and functioning in a way somewhat reminiscent of the monetary functions of central banks. National governments would agree not themselves to issue global emission permits, but to require their nationals to obtain global entitlements for all emissions of specified gases. (Within the constraint imposed by the fixed global budget, individual countries would of course be free to undertake whatever domestic policies they wished to deal with lower-level environmental problems - for example, local tradeable-permit systems to overcome "hotspotting", or regional arrangements to deal with acid rain, would be entirely acceptable provided they did not enable any breach of the global emissions budget.)

(IV.3) The two central features of a workable scheme would be, first, the issuing at international level of a fixed set of emission entitlements (rations) adding-up to 100% of the global emissions budget for the period; and second, the initial allocation of these entitlements to parties other than the polluters, so that each emission source would have to enter the market and pay the full current-market value of its planned emissions. This second point differentiates the proposed regime from the existing US schemes, which allocate permits to existing polluters and then allow newcomers to "buy in". Those schemes have well-known drawbacks in terms of the monopoly position of existing polluters and the non-competitive nature of the bidding process when permits are actually traded. (Lyon 1982; Misiolek and Elder 1989; Hahn 1989).

(IV.4) The simplest and most flexible type of entitlement would give the possessor title to a specified share of the global emissions budget in force at the time for a specified pollutant. Emitters wishing to emit more than one gas would therefore need to possess an appropriate portfolio of entitlements. Global targets could then be revised without having to recall or re-issue any documentation, and target revisions would immediately be reflected in the market value of entitlements. Such a system would immediately allocate any change in global emission targets among permit-holders worldwide, on a transparent basis.

(IV.5) An alternative form of entitlement could carry the right to emit a specified quantity of pollutant at any time prior to expiry of the entitlement. Such a system , however, would be slower to adjust to changes in global targets, although it would enable emitting activities to plan with greater certainty. Systems of this kind have an inherent tendency to act as an upward ratchet on emission levels, suggesting that if at all possible the percentage-share approach of (IV.4) should be used. Furthermore, any uncertainty for polluters operating under a percentage-share system would be merely the global uncertainty about the level of global emissions which proves sustainable; the percentage-share system ensures that the main burden of this uncertainty is carried by polluters, whereas the fixed-quantity approach loads the costs of uncertainty onto the community at large.

(IV.6) Each entitlement should have an expiry date after which it become worthless. These expiry dates could either correspond to the end of the current period, or could extend over several periods (perhaps up to ten years); the latter version, allowing inter-temporal substitution of emission savings, would be more attractive from an economic-efficiency point of view. The rationale for this limited life of permits is to maintain an active market in permits, and to make it far more difficult for any sector or bloc of countries to "corner the market" in the long run. The term of an entitlement should be set at a period roughly corresponding to the investment planning horizon of private-sector firms, so that each generation of investment can be planned in an environment where sufficient emission entitlements can be secured in advance. Annual issues of ten-year entitlements amounting to one-tenth of the global budget would seem consistent with this approach, maintaining the liquidity of the open market while providing scope for forward purchasing as industrial investment plans are carried out.

(IV.7) Entitlements would be freely tradeable in an international market comparable to (possibly integrated with) existing sharemarkets. Governments or private citizens of any country would be free to buy or sell; brokers could operate; and the spot price would float to a current market valuation of marginal emissions. By making the market fully free, issuing entitlements in small divisable units, and giving them a fixed term, it should be possible to prevent any nation(s) or firm(s) from cornering the market; the market would, in other words, be as nearly "perfect" as possible.

(IV.8) The allocation of newly-issued entitlements would obviously carry strong income-distribution overtones, since the initial possessor would be able to lay claim to the market value of the entitlement. Appendix 2 presents a simple economic model to show how rents arise as a result of emission rationing, and how they tend to be distributed under various rationing regimes. In tradeable-permit systems, rents accrue either to the issuing agency (if entitlements are auctioned to capture all rent as seigniorage) or to the first holder of the entitlement. In the scheme considered here, the issuing authority would forego seigniorage and allow the rents to go as transfer incomes to target groups of recipients.

(IV.9) In existing US tradeable-permit systems, and New Zealand fisheries quotas, the tendency has been either to allocate permits pro rata to existing polluters, or to auction them off so that the issuing authority captures the scarcity rents as revenue (Lyon 1982). From equity and incentive points of view, both of these allocation rules are very undesirable. The first gives special insider status to polluters, rewarding them for having invested in environmentally damaging activities, giving incentives for others to do likewise, and enabling insiders to use permits as barriers to entry. The second opens up the risk of revenue-maximising behaviour by the issuing agency. The tasks facing the regulating agency should be clear and unambiguous: to commission sufficient research to set the global pollution budgets within sustainable limits, and to control the total outstanding stock of entitlements within those budgets. Tying the agency's funding directly to its issuing behaviour introduces severe problems of moral hazard which at the very least would damage the credibility of the exercise.

(IV.10) How then should emission entitlements be injected into the world economy? Since the world's rich are the chief polluters of the atmosphere, there are strong equity (and some efficiency) grounds for allocating entitlements initially to the world's poor, so that the necessary purchase of entitlements by the world's polluters would generate a financial flow from rich to poor, hopefully providing resources to encourage development of the poor countries. In practice there would be several complex issues to resolve with any such allocation:

(i) which countries are identified as "poor"?

(ii) are entitlements to be allocated to governments, or other agencies (e.g. voluntary agencies working with the poor in each country) or both?

(iii) should special treatment be given to countries with an established anti-greenhouse stance, or particular large biological sinks (rainforests, for example)?

Such issues, however, are the stuff of international negotiations, and not to be settled *a priori*..

(IV.11) A major attraction of the idea of allocating entitlements to the world market via the poor countries is that it provides a vehicle for resolving several other pressing issues of international policy at the same time as addressing the greenhouse problem. In particular, a mechanism would be opened up for alleviating the position of heavily-indebted countries without in the process discrimminating against those LDCs which have kept themselves free of crippling external indebtedness. While indebted countries would gain servicing capacity, non-indebted countries would gain disposable funding for new investment. In the early stages, financial flows would be relatively small; but as emission limits tightened there would be a rising stream of financial transfers towards LDCs.

(IV.12) An alternative allocation rule would be to treat all citizens of the world as equals, and to allocate entitlements among countries on the basis of population. This would raise the possibility of China and India acquiring a degree of monopoly power in the market, but in general would give a similar result to the first allocation in terms of international financial transfers. It might also be more politically acceptable than a straight grant to "poor countries".

(IV.13) A third possibility would be to allocate entitlements among countries in inverse proportion to their per capita consumption of fossil fuels. This would directly reward those countries which moved seriously to renewable energy, while at the same time helping countries with low levels of development and hence low total energy consumption. It would be more complex to administer than the "poor country" or "population-related" allocations already discussed, and would require an agreed basis for measurement of per-capita pollution. Appendix 3 presents some recent figures on per-capita carbon emissions to illustrate how such an allocation rule might look in practice.

(IV.14) In a perfect theoretical world, emission entitlements could be issued to individual citizens rather than national governments. In practice, market frictions and transactions costs rule this out. However, pursuit of equity goals might suggest that of the "shares" allocated to poor countries, some proportion should go to private or voluntary agencies working mainly with the poor. This could provide a means of encouraging and financing the adoption of small-scale energy-efficient technologies and reducing deforestation pressures in poor countries.

(IV.15) Monitoring and enforcement could be undertaken in a variety of ways. If poor countries received the initial allocation, this would amount to an incentive for each of them to ensure that rich-country polluters were indeed purchasing entitlements appropriate to their emission levels, since this would directly affect the market return from sale of entitlements.

Monitoring arrangements should then emerge spontaneously, with poor-country interests hiring monitoring specialists to identify polluters operating without entitlement. It is likely, however, that some degree of government involvement would be appropriate to supplement such market-driven monitoring. National governments, in particular, could be called on to maintain public registers of entitlement utilization, so that non-government agencies would be enabled to check on compliance by individual polluters.

(IV.16) Verified sinks newly created by investments such as afforestation could earn "credits" in the form either of additional "shares" in the global emission budget, or as a monetary return financed from a levy on entitlement-market transactions. Countries which wished to do so could perhaps be permitted to net new sinks against existing sources, in order to reduce their net requirement for entitlements bought-in on the open market. (This would be an extension of the familiar "bubble" provision in US tradeable-permit schemes.) New sinks which did not permanently neutralise the carbon or other pollutants would, of course, earn only reduced credits, depending on the estimated date at which the pollutants would re-enter the atmosphere (e.g. at harvest and utilisation of trees).

(IV.17) All of these possible ways of rewarding sink preservation or creation, however, are in the nature of *ad hoc* additions to the basic scheme. The emission-permit system is basically a means of targeting policy-determined quantity restrictions on emission sources, and even the most flexible "bubble" schemes to date have allowed only emission reductions, not new sinks, to earn credits (i.e. the right to increase emissions at other sites). Recent trends in the US and Australia point to the emergence of "swap" arrangements, under which new pollution sources will be "neutralised" by the simultaneous establishment of equivalent sinks (usually by afforestation) (F. Pearce 1988; Trexler, Faeth and Kramer 1989; State of Victoria 1989). However, such arrangements seem likely to emerge more for public-relations reasons than because of any monetary incentives for sink creation.

(IV.18) Extending a tradeable-permit scheme to give credit for sink creation or expansion would render the scheme very complex, and make it prone to arbitrary decisions on which (alleged) sinks should qualify for credit. While sink/source swaps are easily identified and monitored at the level of large individual pollution sources, they cannot readily be kept track of at smaller scales of operation; and in any case, to allow polluters to reap commercial benefit from establishing sinks, while denying equal returns to non-polluters who establish sinks, would be economically inefficient as well as inequitable. If, therefore, a tradeable-permit scheme were adopted, the best approach would be to target the permits at gross emissions (i.e. not to allow individual polluters to trade-off new sinks against new sources) while operating a separate, but parallel, policy of incentives for reforestation and other sink-creating activities. Such an arrangement would not be fully optimal, but would constitute a pragmatic response to the administrative problems of targeting net emissions (which would logically have to include credit for negative emissions, i.e. sinks).

(IV.19) There are a number of pitfalls to be avoided in any scheme to subsidise the creation of sinks. Most obvious is the possibility that perverse incentives could be created - for example, to destroy standing rainforest in order to replant the area with high-carbon-absorbing species which could earn higher rents from the subsidy programme. This is an issue which requires more detailed research before clear policy recommendations could be made.

(IV.20) In theory it might seem that a simpler alternative to distributing entitlements would be to allow the international issuing agency to auction the entitlements, and then distribute the proceeds as monetary grants to, e.g., poor countries. In practice, we believe that such a procedure would be a recipe for disaster. First, the moral hazard problem alluded to above (IV.9) is extremely important. Second, by making the actual amounts of money distributed the result of direct administrative decisions, rather than of an impersonal market processes, such an arrangement would expose the agency to pressures which would greatly reduce its flexibility in, and concentration on, its central task of fixing the global emissions budget. Third, an initial auction would open the prospect of rich countries or economic sectors cornering the emissions market at the outset; a major reason for spreading the initial allocation widely among the relatively-disadvantaged is to force polluters into the open market where the poor have the means (by dint of their initial endowment of entitlements) to deal on a relatively equal footing with the rich. Fourth, the timing of the sale, and of the distribution of monetary proceeds, would be dictated by the central agency bureaucracy, rather than leaving timing decisions to the free choice of first-round endowment holders. For most Third-World countries, control over economic processes is at least as important an issue as mere access to cash.

V. LEGALLY-ENFORCEABLE REGULATION OF INDIVIDUAL EMISSIONS

(V.1) A policy regime based on legal enforcement of pollution regulations would begin from an agreement by all participating countries to embody in their domestic legislation a common set of pollution standards. These could take the form either of required ambient standards in the vicinity of any plant, or of quantitative restrictions on the emissions from plants or localities. If it were further agreed that any infringement of the regulations constituted damage to the global commons, it could be open to individuals or organizations of any country to initiate legal proceedings against offending individuals or firms. An international agreement which provided standing for both the global atmospheric monitoring agency, and the citizens of any country, to initiate legal actions, would open the way for regulations to be enforced through the courts at minimum cost to national governments. The agreement would have to specify the jurisdiction under which such cases would be heard (probably the offender's own country, but conceivably a new international environmental court established under United Nations auspices with the consent of all participating countries). Existing practice with regard to the liability of shipowners and shippers for oil spills and other pollution on the high seas could point the way to how such a system might work.

(V.2) Difficulties could obviously arise where governments sought to shield their nationals from legal proceedings. A combination of moral suasion, international odium and time would have to be relied on to deal with such obstacles in the long term.

(V.3) Some authoritative source of evidence of breaches of the agreed limits would be needed. This could come either from national governments, policing the behaviour of their own citizens; or it could involve an international agency, conducting random sampling and publishing the results, while also being available to check any specific source of pollution on request. Non-government agencies, and individuals, could also collect their own evidence.

(V.4) As Appendix 2 demonstrates, a by-product of any policy regime which restricts the quantity of a good reaching the market is the generation of scarcity rents as the price of the good is driven up above its supply cost. If no action is taken to allocate or mop-up these rents, they will accrue to the supplier of the scarce commodity - in this case, to the producer of goods which are jointly produced with greenhouse gases. This problem of windfall rents arising from quantity restrictions has already become apparent in the US chemical industry following the implementation of the Montreal Protocol on CFC reductions, and in response the Environmental Protection Agency has moved towards an auctioned-quota system designed to capture some at least of these rents as government revenue. On an international scale, where the willingness of national governments to apply confiscatory taxation to rents can be expected to vary widely, there is a real danger that transnational corporations may farm-out their polluting activities around the world in order to maximise their excess profits.

VI. "CARBON TAXES" ON KEY POLLUTANTS

(VI.1) The use of Pigovian taxes to fight pollution has increased rapidly in political acceptability in recent decades, due largely to the spread of such taxes in the EEC countries (Opschoor and Vos 1989). Recently, Sweden has imposed a specific "carbon tax" on fossil fuels, and other countries such as the UK (Bendixson 1989) are moving in the same direction. While such country-specific tax interventions make some sense in a situation where unilateral initiatives are the dominant response to the greenhouse problem, there are more difficulties when we turn to the possibility of an international tax regime.

(VI.2) The aim of a pollution tax is to internalise the cost of using fossil fuels and production processes which create large volumes of greenhouse gases. In theory, the tax should be targeted specifically at emissions from each source; in practice a simpler and highly effective approach is to impose taxes at key "gateways" in the production process. Coal can be taxed on a per-tonne-of-expected-emissions basis as it leaves the mine; similarly oil and gas can be taxed at the well-head. Such arrangements are easier to implement than direct emissions monitoring, but are open to the rather important objection that they offer no incentive for users of these fuels to minimise actual emissions.

(VI.3) To avoid sovereignty conflicts, the collecting and enforcing agency would probably have to be the national state apparatus in each country. With tax rates specified administratively in local currency, it would be cumbersome to adjust them continually to maintain constant monetary values in a world of shifting exchange rates. It would therefore probably be most convenient to set each nation an emissions target to be met via use of the tax instrument, and to leave the assessment of local price elasticities, and hence the setting of an appropriate tax rate, to local initiative.

(VI.3) An unfortunate feature of such a regime would be the moral hazard aspect. Any one country, acting alone, would have an incentive to manipulate its tax rate and/or nominal exchange rate, in order to change the real incidence of the "carbon tax" on its domestic producers, and thus give them an increased share of world markets.

(VI.4) The other side of this coin is that any one country acting on its own to impose carbon taxes will be unlikely to have any major impact on global atmospheric trends, because a cut in any single country's share of global fossil-fuel supply can readily be made-up by competing suppliers (Darmstadter and Edmonds 1989, p.46).

(VI.5) A tax regime, thus, would be very difficult to harmonise and monitor on an international scale, because of the problems posed by national sovereignty and the incentives for nations to break ranks. Because there is no world government with taxing powers, pollution taxes will of necessity be designed country by country, by national governments, as a means either of meeting agreed national ambient standards, or of tightening-up the individual country's performance relative to the agreed global standards. (Sweden already uses its domestic tax system in this way, to impose penalties on polluters in advance of a full international agreement.)

(VI.6) If an international regime were to place primary reliance on taxes, some international backstop would be needed to ensure that national authorities had the incentive to impose adequate tax levels. This could take the form of an agreement to impose trade sanctions against the products of countries failing to impose appropriate pollution taxes (see section VII below).

(VI.7) A further major drawback of the tax approach at both national and international levels is the extreme difficulty of setting the right tax rate to achieve quantity targets. In general, taxes are very blunt instruments, being dependent for their impact on elasticities of supply and demand, together with technological and income influences on the relevant markets. Most studies agree that where clear quantity standards can be defined, direct regulation or tradeable permits offer better-targeted means of intervention than taxes.

(VI.8) The major advantage of taxes is the revenue which they generate, which may be earmarked for pollution abatement or research purposes. In fact it is likely that any international policy regime to confront the greenhouse effect will need to operate some sort of levy to finance research and abatement activities. Such levies, however, need not be direct taxes on pollutants. International country-by-country levies on the basis of population or income would be easier to administer and not obviously less equitable (since all people benefit from the research or abatement). Another alternative would be to impose a small transactions tax on all transactions involving the exchange of tradeable permits, under the regime outlined in section IV above.

(VI.9) The use of subsidies as a means of promoting pollution abatement is not recommended. Subsidies to encourage, for example, the installation of pollution-abatement equipment by major polluters, provide no real incentive for them to reduce the polluting activity itself. At the same time, subsidies load the costs of abatement onto taxpayers rather than directly onto the polluters. Appendix 4 provides a simple economic model of these issues. A tax on pollution is both more efficient (because it generates the incentive to reduce the offending activity) and more equitable (the polluter-pays principle) than subsidies.

VII. AN INTERNATIONAL CONVENTION BINDING GOVERNMENTS

(VII.1) The problems inherent in trying to target global measures at individual emission sources are likely to be resolved only in the context of a general international agreement which bound national governments to adhere to, and act in support of, some set of quantitative guidelines. If such agreement is possible, then it is obviously desirable to secure as much mileage as possible from the resulting global accord.

(VII.2) One obvious possibility would be for each country to agree to seek to achieve ambient standards for greenhouse gas concentrations below some specified set of targets. In pursuit of these standards, governments would obviously need to design domestic policy regimes which minimised net GHG emissions, which would provide an obvious and welcome incentive for national governments to provide incentives to encourage sink creation. In regions of contiguous nation-states with problems of transboundary pollution, there would be scope for joint regional action of the sort long discussed in the EEC (e.g. Walter 1975).

(VII.3) Monitoring of atmospheric concentrations in particular countries would be relatively easy provided access was not denied to international observers (note the precedent of recent nuclear test ban agreements). Technology for site-specific monitoring is already well established, and the development of satellite technology for remote sensing of atmospheric composition would permit monitoring on quite a detailed geographical scale.

(VII.4) Achievement and enforcement of an international greenhouse-gas convention will undeniably face considerable problems (cf Darmstadter and Edmonds 1989, pp.46-47).

First, not all countries expect to be losers from greenhouse warming, for the next half-century at least. Many may prefer to take action aimed at adapting to climate change rather than trying to prevent it.

Second, the stakes are higher than in the relatively simple case of CFCs, because of the tighter links between CO_2 emissions and economic growth (although recent scenario analysis indicates that world per capita income could feasibly be trebled by 2050 while cutting CO_2 emissions below current levels)(Darmstadter and Edmonds 1989, p.43).

Third, since the most intense pressure will fall on use of coal, there will be certain countries which see their future growth especially threatened (see Appendix 3). China, India, the USSR and Poland stand out in this group; bringing the first two into any international convention will be a major exercise in diplomacy.

(VII.5) Two types of international action could be relevant in prodding reluctant countries into line: political or diplomatic pressure to induce all nations to conform to internationally agreed standards of environmental protection, and use of economic instruments for the same purpose. The discussion in the remainder of this section will focus on the second of these, taking for granted that the first will be an essential part of any international policy regime.

(VII.6) The rationale for international conventions which set standards for countries to meet, and imposed trade or financial sanctions on offenders, would be similar to that already applying to dumping. Dumping occurs when a country's producers sell their goods on the world market at prices below their true cost of production, usually defined in terms of the market supply price in the country of origin. In the case of greenhouse pollutants, when the production of an export commodity involved greenhouse pollution in excess of internationally-accepted norms, the exporting country could face trade sanctions on the basis of failure to include in the product price the excess cost imposed on the global environment by pollution.

(VII.7) Discussion of trade sanctions has already taken place under the Vienna Convention and Montreal Protocol in relation to products containing CFCs and halons. Sanctions can include imposition of import taxes on the offending products, or on all products from offending countries; or outright bans until the exporter achieves conformity with agreed international standards.

(VII.8) The mechanisms for operating such a system would need to be harmonised with, or even built into, existing trade agreements such as GATT.

(VII.9) The obvious difficulty with a sanctions system is that the countries most likely to offend in the early stages are the possessors of considerable market and political power, and often have relatively low trade ratios (hence relatively low vulnerability to sanctions). A general observation is that the ratio $^{\text{Exports}}/_{\text{GDP}}$ varies widely across countries, and tends to be negatively correlated with GDP (that is, poorer countries tend to be more trade-dependent, as do smaller economies). Important exceptions are China and India, both of which are relatively impervious to sanctions - especially the former at its present stage of development. A system which placed the onus on the weaker countries to impose sanctions on the stronger runs into the problem of incentive incompatibility - namely, that whatever commitments are entered into at the outset, it will not be in the self-interest of the weaker countries to impose sanctions in the face of possible retaliation from the strong.

(VII.10) There is thus a premium placed on world leadership by the great powers in confronting the greenhouse issue. Sanctions regimes work best when deployed by the strong against the weak. They have potential value as a means by which a majority coalition of nations could pressure particular recalcitrant countries into line, but they are of most obvious relevance in a situation where the great powers take a leadership role in combating the greenhouse effect, and set out to persuade other nations to join them.

VIII. CONCLUSION

(VIII.1) This paper has undertaken only a preliminary reconnaissance of a very large field. We were disappointed not to find more systematic discussion of the operation of international regulatory instruments in the economics and environmental-science literature. It is possible that a survey of the literature in international law would yield at least some important principles and precedents, and possibly some detailed consideration of the concrete steps required to establish international policies on the greenhouse problem. In the time available for preparation of this paper we were not able to undertake such a survey.

(VIII.2) Our consideration of four policy options for restricting emissions suggests that the two instruments most often found in national regulatory systems - detailed quantity limits for individual sources, and use of pollution taxes - were the two which appear least attractive when carried across to the international setting. In contrast, the tradeable-permit concept, which has had a difficult early life in practice in the USA and New Zealand, seems to offer much greater scope for successful application as an international instrument operating under the umbrella of an international convention on greenhouse gases. A regime which legitimated a set of internationally-tradeable emission entitlements to restrict gross emissions, while at the same time driving pollution prices to levels sufficient to induce large-scale substitution towards energy-saving and renewable energy systems, could open the way to solving other pressing international issues of poverty and indebtedness. Backed up by the credible threat of collective sanctions against offenders, and supplemented by (unavoidably ad hoc) policies to encourage sink creation, such a policy regime could point the world economy towards achievement of reasonable growth aspirations while at least limiting, and hopefully reversing, the buildup of greenhouse gases. Scenario analysis points to the feasibility of such an outcome (Damstadter and Edmonds 1989; US-Netherlands Experts Group 1989), and the time scales involved are long enough to permit the emergence of an international consensus, and some early experiments with alternative policy instruments and new institutions.

(VIII.3) We would emphasize that the four main options canvassed in this paper should not be interpreted as mutually-exclusive alternatives. We have taken a broad approach which tries not to deal with "economic instruments" in isolation from other elements of a realistic policy package, and we doubt that any single policy could, on its own, be successful in tackling the complexities of the greenhouse issue. In terms of the principles outlined in II.3, none of our options on its own meets all seven. (Our preferred version of the tradeable-permits approach, if buttressed by international legal conventions, comes closest to doing so but fails to offer any means of encouraging sink creation in other than an *ad-hoc* manner.)

(VIII.4) There remain enormous problems to be confronted merely to negotiate and implement any international agreement. The precise nature of the institutions required, and their relation with existing international organisations and agencies, is still unclear. The problem of securing consensus in a world where there are both winners and losers in virtually any scenario remains daunting. Ironically, however, it may be easier to secure agreement now, when uncertainties are very great, than later on when the scientific evidence on the details of climate change firms up and individual countries become able better to determine whether they fall into the winner or the loser category.

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Appendix I
Basic Data on Greenhouse Effects: Some Tables and Charts from the Recent Literature

Darmstadter and Edmonds (1989) pp.37 & 38:

Table 3-1. Annual Emissions Budget Estimates for Seven Radiatively Important Gases

Source	CO_2[a] (MtC)	CO[b] (MtC)	CH_4[c] (MtC)	N_2O[b] (MtN)	NO_x[b] (MtN)	$CFCl_3$ (Mt)	CF_2Cl_2 (Mt)
ENERGY	4,846	240	50	4.0	26.0	—	—
Production							
Gas	96	—	20	—	—	—	—
Coal	—	—	10	—	—	—	—
Storage	—	40	—	—	—	—	—
End use							
Residential/Commercial }		100	20	0.4	1.1	—	—
Industrial }	3,400	10	—	1.2	4.1	—	—
Transport }		90	—	—	11.2	—	—
Utilities	1,350	—	—	2.4	9.6	—	—
LAND-USE CHANGES	1,300	160	20	0.5	—	—	
AGRICULTURE	—	110	175	1.3	6.0	—	—
Savanna burning	—	110	30	0.4	6.0	—	—
Rice	—	—	70	—	—	—	—
Fertilizer	—	—	—	0.8	—	—	—
Cultivated soils	—	—	—	1.5	—	—	—
Cattle	—	—	75	—	—	—	—
CHEMICAL MANUFACTURE	—	—	—	—	—	0.33	0.44
Refrigeration	—	—	—	—	—	0.03	0.22
Foam-blowing uses	—	—	—	—	—	0.18	0.06
Aerosol spray uses	—	—	—	—	—	0.10	0.14
Miscellaneous uses	—	—	—	—	—	0.02	0.03

Notes: Confidence intervals are given in Wuebbles and Edmonds (1988). MtC = million tons carbon; MtN = million tons nitrogen; Mt = million tons; dashes denote zero or not significant.

Source: Wuebbles and Edmonds (1988).

[a]Carbon dioxide emissions figures are based on the total carbon content of the fuels and biomass stocks oxidized, without reference to the initial form that the carbon takes (that is, whether the carbon appears initially as CO, CH_4, CO_2, or some other carbon compound). This convention is adopted on the grounds that all carbon compounds eventually oxidize to CO_2. In principle, the emissions figures for CO and CH_4 refer to gross releases of carbon in those forms over the course of a year and make no reference to transformations of carbon from other states into CO or CH_4 or transformations of CO or CH_4 into other compounds. There is, therefore, an inconsistency between the accounting conventions used for CO_2 and those for CO and CH_4.

[b]Energy data are disaggregated on the basis of information from Kavanaugh (1987) but are scaled to match totals given in Wuebbles and Edmonds (1988).

[c]Energy data are disaggregated on the basis of information from Edmonds and Marland (1986) but are scaled to match totals given in Wuebbles and Edmonds (1988).

Table 3-2. Average CO_2 Emission Coefficients by Fuel

Fuel	gC/Mj[a]	gC/kBtu[a]
Oil	19.2	20.256
Gas	13.8	14.4535
Coal	23.8	25.109
Shale[b]	27.9	29.4345

Source: Reprinted, with permission, from Edmonds and Reilly (1985), p. 266.

[a]The first column shows grams of carbon per megajoule, or million joules; the second column shows grams of carbon per thousand British thermal units (Btu). One Btu equals 1,055 joules.

[b]Shale refers to the mining of oil shale found in carbonate rock formations.

Appendix I (cont)

Darmstadter and Edmonds (1989) p.39:

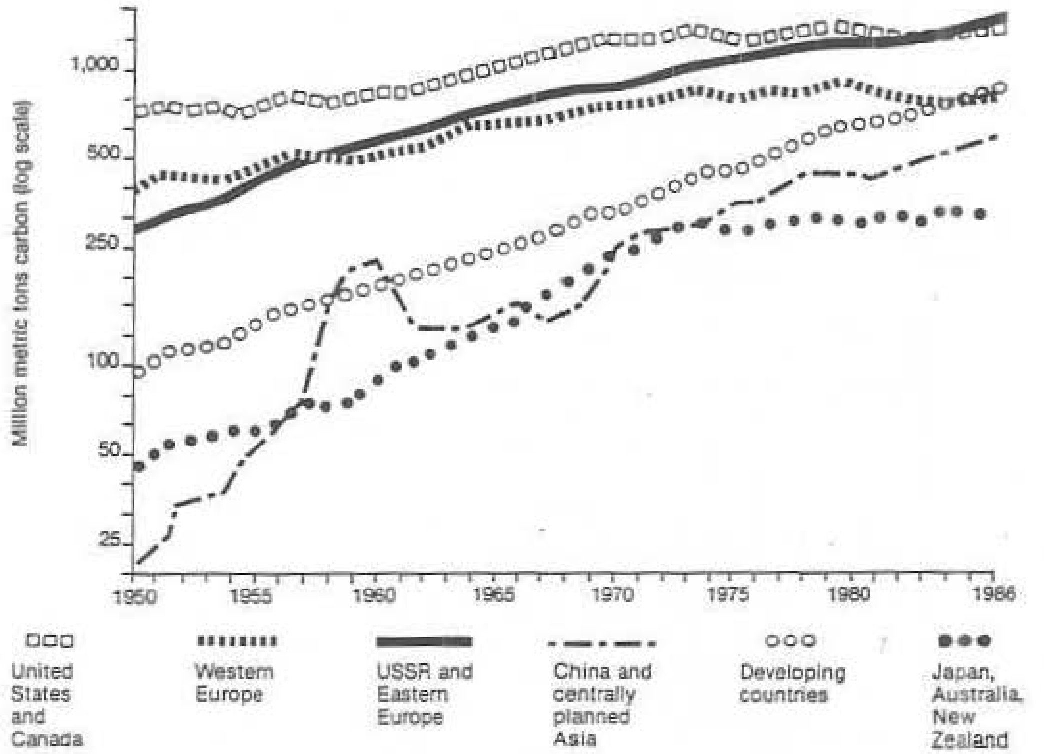


Figure 3-1. CO_2 emissions from fossil fuel combustion by major world regions, 1950–1986. *Note:* "Developing countries" represent the difference between the worldwide total (figure 3-2) and the sum of the other regions shown. They thus include several countries—e.g., South Africa—not normally classified as "developing." (*Source:* Data prepared by and obtained from Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1988.)

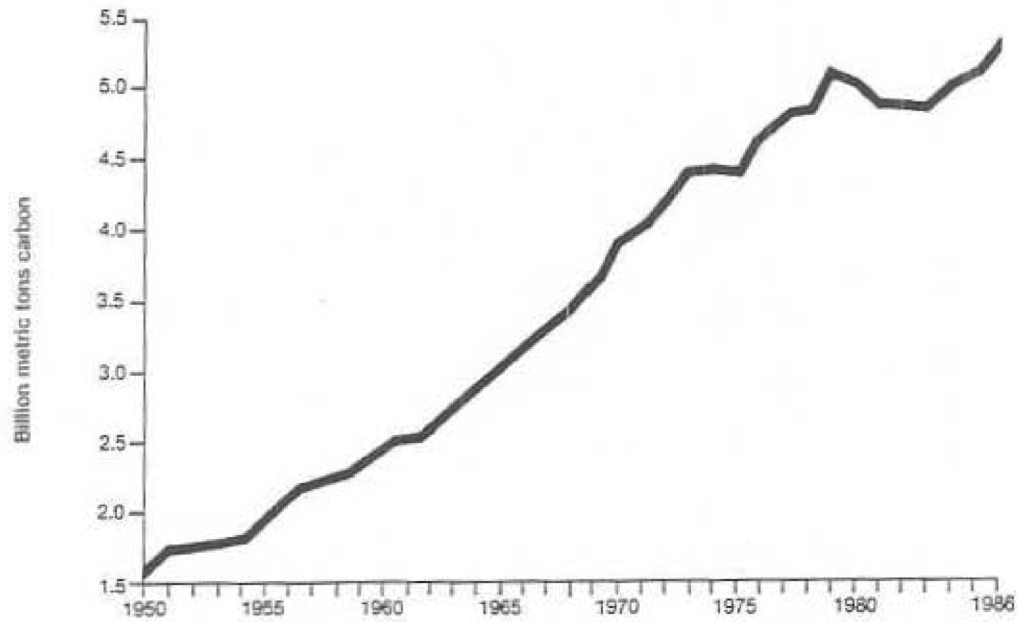


Figure 3-2. Total global CO_2 emissions from fossil fuel combustion, 1950–1986. (*Source:* Data prepared by and obtained from Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1988.)

Appendix I (cont)

Darmstadter and Edmonds (1989) pp.42 & 43:

Table 3-4. Reference Case Forecast

Category	1975	2000	2025	2050	2075
Fossil fuel CO_2[a]	4.5	5.8	6.9	7.7	8.5
Total primary energy[b]	235	380	525	672	821
Conventional oil	100	148	148	152	106
Unconventional oil	0	0	0	0	1
Natural gas	39	42	85	110	79
Coal	75	107	124	131	185
Biomass[c]	0	14	24	41	63
Nuclear[d]	4	7	20	29	61
Solar[d]	0	0	1	1	3
End-use energy[b]	178	278	366	416	465
Electricity[b]	24	41	69	97	133
GNP[e]	6	14	30	60	112
World price of oil[f]	1.84	2.29	3.52	3.95	4.89

Source: Median values taken from Edmonds et al. (1986).

[a]Expressed in gigatons of carbon per year (GtC/yr). A gigaton = 1 billion metric tons.

[b]All primary energy categories, end-use energy, and electricity are shown in exajoules (1 EJ = 10^{18} joules). Individual energy subcategories do not sum to total primary energy due to the exclusion of hydroelectric power generation and the use of median values of output from 400 runs in the uncertainty analysis.

[c]Includes only biomass from waste and biomass plantations. Excludes traditional biomass.

[d]Primary energy equivalent.

[e]10^{12} 1975 U.S. dollars.

[f]1975 U.S. dollars per gigajoule. (A dollar per gigajoule—that is, per billion joules—is the equivalent of about $5.50 per barrel of oil in 1975 prices. Thus, $3.95 per gigajoule in the year 2050 is the equivalent of about $22 per barrel of oil in 1975 prices or $44 per barrel in 1987 prices.)

Table 3-5. Uncertainty Range in Global Fossil Fuel CO_2 Emissions, 2000–2075 (gigatons of carbon per year [GtC/yr])

Year	5%[a]	25%[a]	50%[a]	75%[a]	95%[a]
2000	3.2	4.6	5.8	7.7	14.2
2025	2.4	4.5	6.9	13.0	29.8
2050	2.3	4.3	7.7	18.7	58.1
2075	1.8	3.9	8.5	27.1	86.9

Source: Edmonds et al. (1986). See accompanying text for comments on the uncertainty analysis.

[a]The percentage of 400 runs for which CO_2 emissions were less than the values shown. For example, the 25% column shows that 25% of 400 forecast runs had CO_2 emissions lower than 4.6 billion tons per year (Gt/yr) in the year 2000 and lower than 3.9 Gt/yr in the year 2075.

Table 3-6. Demographic, Economic, Energy, and CO_2 Data for 1985 and for Alternative Scenarios in 2050

		2050		
	1985[a]	Reference case[b]	Constant emissions[c]	Declining emissions[d]
Population (billion)	4.8	9.2	9.2	9.7
GNP (index)				
Total	100	683	683	495
Per capita	100	359	359	247
Total primary				
energy consumption (EJ)	323	672	583–672	354
Fossil fuels	262	393	304	179
(Coal)	(89)	(131)	(42)	(23)
(Oil and Gas)	(172)	(262)	(262)	(156)
Nonfossil fuels	61	279	279–368	175
CO_2 emissions (GtC/yr)[c]	5.2	7.7	5.2	2.5

Note: See text for further discussion of this table.

[a]Population and energy data from United Nations statistical sources. Worldwide GNP assumed to lie on trend line shown in table 3-3. CO_2 emissions based on table 3-2.

[b]Reference case taken from median values given in table 3-4.

[c]Constant emissions case derived by assuming the level of oil and gas availability given in table 3-4. Associated CO_2 emissions are derived by assuming that on average 7 percent of all oil is diverted to nonfuel uses that delay oxidation and by applying the CO_2 emissions coefficients given in table 3-2. Carbon emissions are 2.7 GtC/yr for oil and 1.5 GtC/yr for natural gas. The restriction of total emissions to 5.2 GtC/yr implies that coal emissions be constrained to 1.0 GtC/yr, or coal use cannot exceed 42 EJ/yr. In the low-range total energy and nonfossil fuel figures, we assume that the same contribution is available from nonfossil energy sources as in the reference scenario. This implies that total energy use would be 583 EJ and that the rate of reduction in energy intensity must increase from an average rate of 1.8 percent per year to 2.0 percent per year to maintain the same population and economic growth as in the reference scenario. In the high-range total energy and nonfossil fuel figures, we assume that overall energy intensity lacks this additional flexibility and that, therefore, the CO_2-constrained limit on fossil fuel use must be fully offset by recourse to nonfossil fuels.

[d]Declining emissions case taken from Mintzer (1987).

Appendix I (cont)

Karas and Kelly (1988) p.9:

Table 2.1

The sources of the major greenhouse gases.

Carbon dioxide	Fossil fuel combustion, deforestation and other forms of changing land use, biomass burning, erosion
CFCs	Various industrial processes and applications (see Table 2.5)
Methane	Biological decay in water-logged areas (such as rice paddies) and animal waste, enteric fermentation in cattle and termites, biomass burning, oil and gas exploitation
Nitrous oxide	Fertilizer use, fossil fuel combustion, biomass burning, changing land use
Ozone	Reactions involving other pollutants (carbon monoxide, methane and other hydrocarbons and nitrogen oxides) and sunshine

Table 2.2

Past and present levels of the greenhouse gases, present release rates and residence times. It is difficult to assign meaningful global levels in the case of ozone. The growth rates are for the period 1980-87.

	Pre-industrial concentration	1985 concentration	Growth rate	Residence time
Carbon dioxide	275ppmv	346ppmv	0.5%/yr	7yr
CFC-11	-	0.22ppbv	6.1	75
CFC-12	-	0.37ppbv	6.2	111
Methane	700ppbv	1650ppbv	1.0	10
Nitrous oxide	280ppbv	309ppbv	0.4	170

Appendix I (cont)

Schneider and Rosenberg (1989) pp.9 & 21:

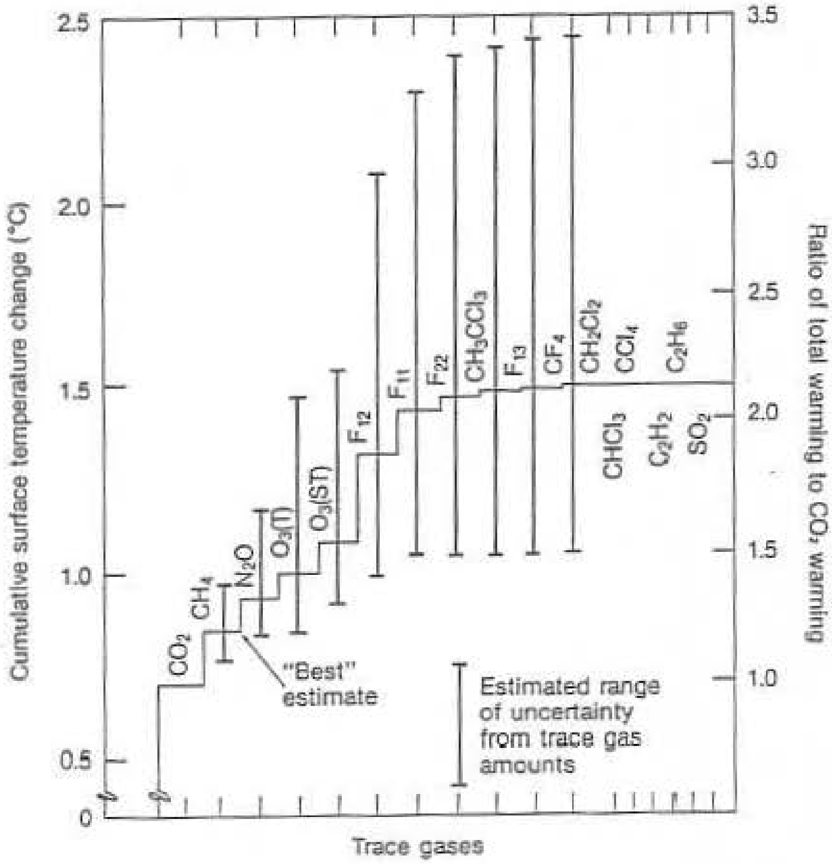


Figure 2-2. Cumulative surface warming from assumed trace gas scenario. (Period fifty years from 1980 levels.) (*Source:* Adapted, with permission, from V. Ramanathan et al., "Trace Gas Trends and Their Potential Role in Climate Change." *Journal of Geophysical Research* vol. 90, pp. 5547–5566. © 1985 by the American Geophysical Union.)

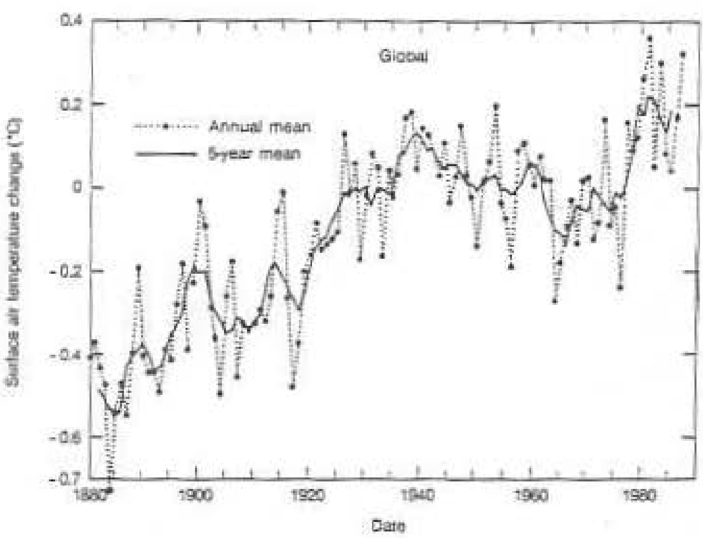


Figure 2-9. Global surface air temperature calculated from land stations over the past century. (*Source:* Reprinted, with permission, from J. Hansen et al., "Climate Impact of Increasing Atmospheric Carbon Dioxide," *Science* vol. 213, pp. 957–966. © 1981 by the AAAS.)

Table 2-1. Projections of Climatic Changes Likely to Occur as the Result of an Equivalent Doubling of Atmospheric CO_2

Phenomenon	Probable global annual average change	Distribution of change: Regional average	Distribution of change: Change in seasonality	Interannual variability[a]	Significant transients	Confidence of projections: Global average	Confidence of projections: Regional average	Estimated time for research that leads to consensus (years)
Temperature	+2°C to +5°C	−3°C to +10°C	Yes	Down?	Yes	High	Medium	0-5
Sea level	+0.1 m to 1.0 m	[b]	No	[c]	Unlikely	High	Medium	5-20
Precipitation	+7% to +15%	−20% to +20%	Yes	Up?	Yes	High	Low	10-50
Solar radiation	−10% to +10%	−30% to +30%	Yes	[c]	Possible	Low	Low	10-50
Evapotranspiration	+5% to +10%	−10% to +10%	Yes	[c]	Possible	High	Low	10-50
Soil moisture	—[c]	−50% to +50%	Yes	[c]	Yes	[c]	Medium	10-50
Runoff	Increase	−50% to +50%	Yes	[c]	Yes	Medium	Low	10-50
Severe storms	[c]	[c]	[c]	[c]	Yes	[c]	[c]	10-50

Note: Equivalent doubling means that point where carbon dioxide and other trace greenhouse gases have a radiative effect equivalent to doubling the pre-industrial value of carbon dioxide.

Source: Adapted, by permission of the American Association for the Advancement of Science, from L. Mearns, P. H. Gleick, and S. H. Schneider, "Prospects for Climate Change," in Paul Waggoner, ed., *Climate Change and U.S. Water Resources* (New York, Wiley for AAAS, forthcoming), table 1.

[a] Inferences based on preliminary results of Rind et al. (forthcoming).

[b] Sea-level increases at approximately the global rate except where local geological activity prevails.

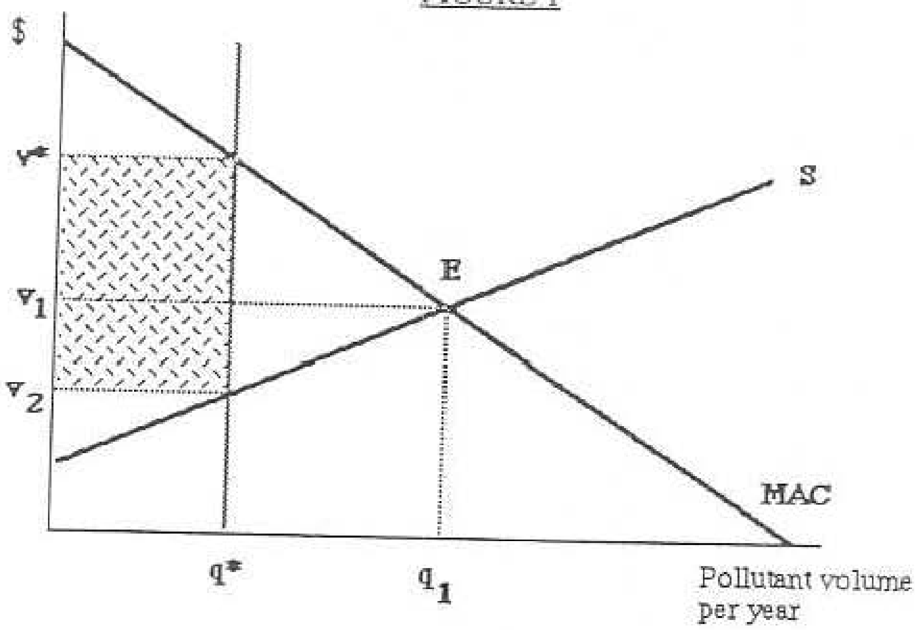
[c] No basis for quantitative or qualitative forecast.

APPENDIX 2
A Simple Economic Model for Comparing Policy Regimes.

Figure 1 below provides a very general stylised model of the impact of policies to deal with the greenhouse problem. The downward-sloping MAC (Marginal Abatement Cost) curve represents the world economy's demand for greenhouse gas emissions; this curve can be thought of as portraying emitting activities ranked in terms of a composite measure (marginal abatement cost) that incorporates their dispensability (opportunity cost) and substitution possibilities (cost of switching to backstop, non-polluting, technologies) at a given level of world GDP and with given technology.

The private supply curve S shows the long-run supply price of polluting substances embodied in fossil fuels, assuming no constraint on the use of these fuels. The present position of the world economy is then represented by point E.

FIGURE 1



Suppose that the emissions target set for, say, 2005 is q*, and a policy regime is instituted which imposes an annual cutback along some path over the intervening fifteen years. Then in the year 2005 the world economy would be constrained to operate at q* volume of annual net emissions. If there were no economic growth over the period (or if energy-saving technological progress exactly offset the tendency of growth to shift the MAC curve to the right) then the marginal value attached to the use of polluting fuels would be v*. This is closely related to Pearce's concept of the "sustainable optimal price" (D. Pearce 1988, p.64).

The scarcity rental rate arising from the rationing of pollution volume will be $(v^* - v_2)$ per unit, with total rents shown by the shaded area. In essence there are four potential claimants of this rent: the polluters, national governments, international agencies, and others.

Under a simple quantitative legal restriction, the rent accrues to the producers of pollutants, who receive a price v* for their products compared with their marginal private cost of v_2. In a world of imperfect competition, the rent may be shared with consumers.

Under a carbon-tax regime, the rent accrues as revenue to national governments. (The same occurs if quantity permits are auctioned off.)

Under a tradeable-permit regime, the rent acrues to whoever has first right to sell the permits - either the issuing agency (insofar as this agency claims seignorage) or the parties to whom the permits are issued in the first instance.

The distributive effects thus provide an important theoretical distinction among the regimes - although practical considerations of transaction costs and administrative inflexibility come to the fore in a realistic comparison.

APPENDIX 3

Allocating Tradeable Permits According to Emission Status, and Coal Production: Some Figures.

In this appendix we present two sets of data. First, we take Bolin's estimates of CO_2 emissions per inhabitant, which enable us to show how the alternative formulae for allocating emission entitlements (sections IV.10-IV.13) might look in practice if applied to CO_2. Second, we reproduce some figures on the world distribution of coal production, to identify the countries which would be most severely affected by a global regims to phase out coal from the world energy system.

Country-by-Country CO_2 Emission Status

Table A3.1 uses Bolin's figures for per capita emissions, and population data from the World Bank database, to allocate the world's 4.9 gigatons of annual carbon emissions among countries, ranking them in order of per capita emissions.

TABLE A3.1

Carbon Dioxide Emissions and Population, by Country, mid-late 1980s

Country	Per capita carbon emissions (tons)	Population (millions)	Total carbon emissions (000 tons/year)
USA	4.9	241.6	1,183.8
East Germany	4.9	16.6	81.3
Canada	4.4	25.6	112.6
Czechoslovakia	4.1	15.5	63.6
Australia	3.9	16.0	62.4
USSR	3.3	281.1	927.6
Poland	3.0	37.5	112.5
West Germany	2.9	60.9	176.6
UK	2.5	56.7	141.8
Netherlands	2.5	14.6	36.5
Sweden	2.2	8.4	18.5
France	2.0	55.4	110.8
Japan	1.9	121.5	230.9
Italy	1.5	57.2	85.8
Spain	1.4	38.7	54.2
People's Republic of China	0.5	1,054.0	527.0
Brazil	0.3	138.4	41.5
India	0.1	781.4	78.1
Other	0.5	1,868.3	843.9
World Total	1.0	4,889.4	4,889.4

Sources: Bolin (1989) Table 4 p.10; population from World Bank, *World Development Report 1988*, Table 1.

Table A3.2 then shows how tradeable entitlements to the same total of 4.9 gigatons might be allocated among the same countries on the following bases:

(1) Countries classed "developing countries" by the World Bank share out the world's entitlements in inverse proportion to each country's population-weighted share of total GNP for the group.

(2) Entitlements are distributed to countries on a straight per-head-of-population basis of 1 ton of carbon per head per year.

(3) Entitlements are distributed according to an index which relates each country's actual emissions to its quota under (2), to give a merit "scale" of emission-saving, and sets the USA's allocation (the lowest point on the scale) to zero.

Table A3.2
Some Hypothetical Emission Entitlement Allocation Schemes in Operation
Thousands of Tons of Carbon Entitlement by Country

Country	Allocation scheme (1) "The Poor"	Allocation scheme (2) Per Head	Allocation scheme (3) By Emission Status
USA	0	242	0
Democratic Republic of Germany	0	17	0
Canada	0	26	6
Czechoslovakia	0	16	10
Australia	0	16	13
USSR	0	281	25
Poland	0	38	32
West Germany	0	61	35
UK	0	57	49
Netherlands	0	15	49
Sweden	0	8	63
France	0	55	74
Japan	0	122	81
Italy	0	57	116
Spain	0	39	128
People's Republic of China	1815	1054	451
Brazil	5	138	787
India	1032	781	2463
Other	2037	1868	505
World Total	4889	4889	4889

Perhaps the most interesting result, from the point of view of the political economy of diplomacy, is the way the choice of allocation schemes shifts the balance of advantage between China and India, the "big two" poor countries.

World Coal Data

Table A3.3
Coal Output Data for 1986

Region/Country	Millions of metric tons	
	Hard Coal	Brown Coal
TOTAL WORLD	3,193.4	1,225.6
OECD	1,159.5	353.4
Australia	133.4	36.1
Canada	30.5	26.5
West Germany	87.1	114.4
Greece	-	38.1
Spain	-	22.4
UK	108.1	-
USA	738.9	66.8
Other OECD	61.5	49.1
NON-OECD	2033.9	872.2
AFRICA	186.1	-
South Africa	176.7	-
Zimbabwe	3.0	-
Other Africa	6.4	-
ASIA	1,081.8	69.1
China	840.0	36.0
India	166.0	9.6
North Korea	39.5	12.5
South Korea	24.3	-
Other Asia	12.1	11.0
USSR	510.9	159.2
EAST EUROPE	229.4	543.3
Bulgaria	-	35.0
Czechoslovakia	25.7	100.3
East Germany	-	311.3
Hungary	-	20.8
Poland	192.1	67.3
Romania	8.7	38.0
Other East Europe	2.9	70.7
CENTRAL AND SOUTH AMERICA	25.8	-
Brazil	7.4	-
Colombia	10.7	-
Mexico	5.5	-
Other C & S America	2.1	-

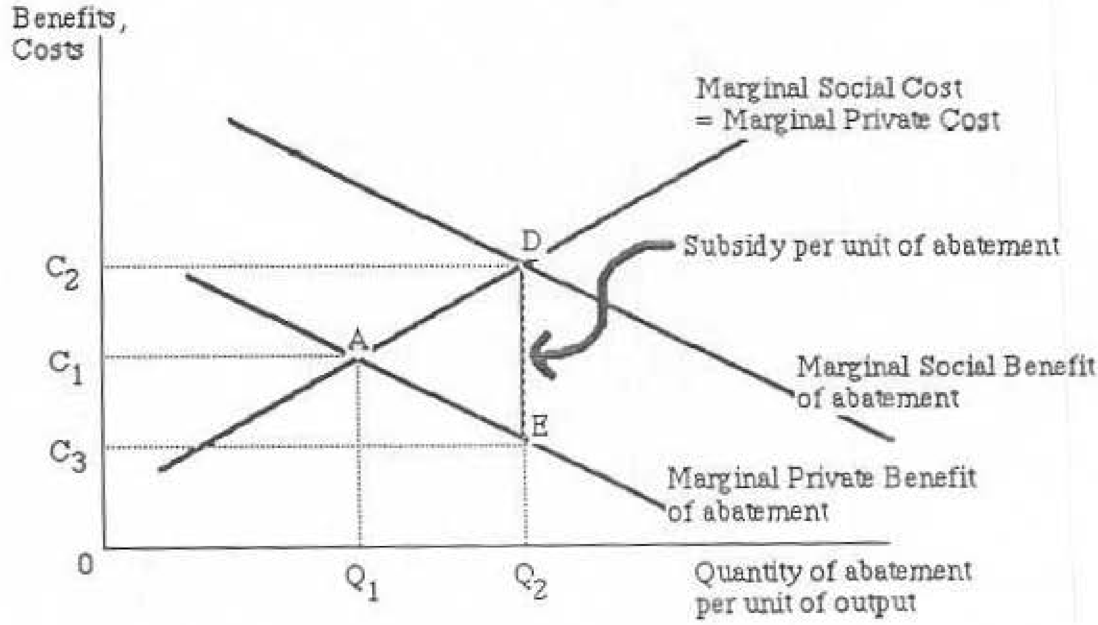
Source: OECD International Energy Agency, *Coal Information 1988* , Tables 5.1 and 5.2.

APPENDIX 4

Problems with the Use of Subsidies to Promote Abatement.

Figure A4.1 shows the marginal costs and benefits, both private and social, of abatement activities such as the installation and operation of flue-scrubbing equipment. Assuming that the social benefits from abatement exceed the private benefits, the free-market outcome of OQ_1 of abatement, at a cost to polluters of C_1, involves polluters undertaking less than the optimal amount of abatement and facing less than the socially-efficient level of cost. The optimum is OQ_2 of abatement, at a marginal cost of C_2. A subsidy of the amount DE would achieve the socially-efficient level of abatement, but would leave polluters facing the subsidized cost C_3. Because the full cost of abatement is thus not internalised by polluters, there is no incentive for them to cut back on the activity which caused the pollution problem in the first place, while the costs of the abatement subsidy fall on taxpayers.

FIGURE A4.1



A tax on the pollution emissions themselves, in contrast, forces polluters to internalise the social costs of pollution. Under such a tax regime, the marginal-private-benefit-of-abatement curve is shifted out. If the tax is at exactly the right level, MPB will coincide with MSB and polluters will voluntarily undertake the optimal amount of abatement. In practice, such precision is not generally attainable in the use of the tax instrument, but this is no reason to switch to a subsidy system which is just as difficult to calculate and target effectively.