SOME POLICY ISSUES OF GREENHOUSE GAS ECONOMICS

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CONTENTS

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ABSTRACT

Climate changes due to emissions of greenhouse gases, (GHGs) is a long-term global environmental problem. Major policy issues relate to the question of the appropriate negotiating stance in possible multilateral negotiations for an international protocol on GHGS. This paper discusses a few models designed to help policy-makers evaluate the likely economic impacts of various schemes for assignments of net emissions quotas.

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1INTRODUCTION

Despite considerable uncertainty some scientific consensus exists at present regarding the environmental consequences of the greenhouse effect. Briefly, it is that large scale, mostly adverse, environmental impacts can be expected to occur, in a time-span extending to the next few human generations. These impacts may require costly economic and societal adjustments.

The major offset to the generation of carbon dioxide, the most significant of the greenhouse gases (GHGs), is forests. Trees convert atmospheric carbon dioxide to biomass and oxygen through photosynthesis, and are thus a crucial element in maintaining the composition of the atmosphere. Further, deforestation through burning of forest cover generates significant quantities of carbon dioxide, and additional quantities are released from tillage of the soil. Loss of forests also increase the albedo (reflective power of the earth) since forests are dark and absorb a high proportion of solar radiant energy. Deforestation also reduces rainfall, with further potential impacts on atmospheric behaviour. Although forests now cover only 20 percent of the earth's land surface, they produce 75 percent by weight of bio-mass. Since the 1950s, extensive deforestation of tropical forests has taken place, to the extent of 25 - 40 percent of the pristine cover, and continues at an estimated annual rate of 80,000 square kilometres - an area the size of Austria. (World Resources, 1987). Current deforestation levels and changing land use patterns are estimated to contribute between 10 and 50 percent of the carbon dioxide from fossil fuel emissions, (Boyle and Ardill, 1989, p.34). While large scale deforestation in itself has major environmental impacts: reduction in fuelwood supplies, loss of genetic resources, soil erosion, silting of reservoirs and flooding, its impacts on net GHGs emissions are also very significant. Clearly, there are important complementarities between these two sets of problems. One string of present research thus links emissions of greenhouse gases with their offset by forests, in both domestic and international regulatory approaches. This is accomplished by allowing domestic industries to purchase offsets from the forest sector to reduce their penalties for emissions, or to enable them to use greater quantities of energy. Economy wide, any excess of allowable national emissions over the quantity actually emitted, after allowing for offsets generated, is allowed to be traded internationally by the government. Since a major source of GHGs is the use of fossil fuels, improved energy efficiency and switch to alternative fuels form another important set of related issues. Fossil fuel use is also an important determinant of local and regional air quality, through particulate, nitrogen oxides (NO_x), and sulphur (SO_x) emissions. While there are several important complementarities between increased energy efficiency, local and regional air quality, and GHGs emissions, there are other policy considerations which conflict with these objections. Thus, for example, many countries including several industrialized countries (INCs) and newly industrialized economies (NIEs), are dependent on imported oil, but have relatively abundant reserves of other energy sources, such as coal, hydroelectric potential, and nuclear fuel material. World oil prices in the recent past have fluctuated widely, and adjustments to rapid price increases can prove disruptive and costly for national economies. An important policy objective in several countries is reduced dependence on imported oil, largely by substitution by domestic energy supplies. However, these alternative fuels may have other, major adverse impacts of their own. Substitution of oil by coal often results in increased CO_2, NO_x, SO_x, and particulates emissions, while hydroelectricity may displace large populations from reservoir sites and may lead, in vulnerable areas, to increased seismic risks. Nuclear energy entails major long-term safety and health hazards, through generation of long lived radioactive wastes, potential explosive fissile material which may increase the risks of acquisition of `basement' nuclear weapons by insurgents, and due to decommissioning of old reactors.

The Villach-Bellagio conference, as part of its policy recommendations, called for intensification and development of non-fossil fuel energy systems, support for reduction in deforestation and increase in forested areas, and examination by organizations, of the need for an agreement on a law of the atmosphere as a global commons or the need to move towards a convention along the lines of that developed for ozone. A subsequent conference at Toronto in June 1988 was more explicit in its policy recommendations.[i]

First the Toronto conference took the unambiguous position that: `Humanity is conducting an uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war', and that `the best predictions available indicate potentially severe economic and social dislocation for present and future generations which will worsen international tensions'. Second, that the industrial countries are the main sources of greenhouse gases and therefore bear the main responsibility to the world community for ensuring that measures are implemented to address the issues posed by climate change. At the same time, the developing countries must be assisted and not inhibited in improving their economies and the living conditions of their citizens. This will necessitate a wide range of measures, including significant additional energy use in those countries and compensating reductions in industrialized countries. Further, that while the first steps in developing international law and practices to address air pollution have already been taken. (Principle 21 of the 1972 Stockholm Declaration, the ECE Convention on Long Range Transboundary Sir Pollution for Sulphur Reductions, 1985. Part XII of the Law of the Sea Convention, and the Vienna Convention for Protection of the Ozone Layer and its Montreal Protocol, 1987), member governments of the UN system and international bodies should initiate the development of a comprehensive global convention as a framework for protocols on the protection of the atmosphere. Additionally, the Toronto conference concluded, energy policies must be designed to reduce emissions of CO_2 and other trace gases by more than 50 percent in the long-term, and initially, by about 20 percent of 1988 levels by the year 2005.

2 LIKELIHOOD OF AN INTERNATIONAL AGREEMENT ON GHGS

What, in fact, is the likelihood that an international protocol for regulating GHGs will actually be negotiated and implemented? In order to answer this, one may note the emergence of a framework for analyzing issues relating to international regulation of the environment (Hahn and Richards, 1988). According to this framework, the probability of reaching an agreement on an international environmental issue will increase with greater scientific consensus on the cause and seriousness of the problem, increased public concern, a perception that negotiating parties are doing their `fair' share to mitigate the problem, and an increase in the short-term political benefits from reaching an agreement. The probability of agreements will decrease as the costs of control increase and as the number of negotiating parties increases. The effect of increased monitoring and enforcement powers is ambiguous.

In the case of climate change due to GHGs, scientific consensus largely exists regarding the causes, but not on the extent or seriousness of the effects. (Lunde, 1991). Further, actual reductions in GHGs emissions will very likely entail major long-term economic costs. Regarding the benefits of control measures, at this point it is not possible to predict their distribution, except that they are likely to be very uneven. This fact will complicate the perceptions of `fairness' of control proposals. Finally, the level of public awareness and concern has been increasing in some countries, but is as yet, worldwide, far below the level at which significant economic costs would be countenanced, or the political benefits of an agreement be attractive. Hahn and Richards (1988) conclude that `the likely response will be a series of informal and formal meetings aimed at sharing and disseminating research findings, and giving the appearance of making progress on this very difficult issue. Only when a much higher level of scientific consensus emerges will the difficult economic sacrifices become tenable.' Lave (1988) observes that because of the greater uncertainties involved in the greenhouse effect, policies should be formulated so that they `are unlikely to be harmful or costly if the greenhouse consequences are more benign than predicted and likely to help if the worst happens'. Schelling (1988) suggests that substantial near term reductions of GHGs emissions are unlikely since countries have already failed to reduce consumption of fossil fuels, despite ample motivations for increasing energy efficiency. This discussion, thus, underscores the importance of evaluating the long-term economic costs of various alternative policies at the national level to precede serious negotiations for an eventual GHGs treaty. (Hoel, 1991.)

Several types of policy instruments, operating nationally, as well as internationally, have been suggested for tackling the problem of the greenhouse effect. Several of these are intended to work through economic incentives, while others rely on directives. The markets may be global, regional, or national, and include trades in permits and offsets. The directives may be at the level of individual states, or at a multilateral level, by agreement between sovereign states.

3 TYPES OF POLICY INSTRUMENTS

Some of the policy instruments which have been discussed in the literature are examined here. The first set of policies are intended to work at the national level, and the second, internationally.

3.1 National Level Policies

It is widely recognized that inefficient energy use results largely from widespread subsidies on energy use in many countries, and additionally, from the failure of markets to reflect the full social costs of energy use, including environmental externalities. Low energy prices encourage substitution of energy for other scarce factors, chiefly capital or labour, or both. Consequently, there are increased emissions of GHGs and other pollutants. Also, if imported oil is cheap relative to domestic energy sources, this price differential encourages dependence on imported oil. Further, the use of renewable energy sources, for example, solar or wind energy devices, which in general are non-polluting, is also discouraged by low relative prices for fossil or nuclear fuels. Thus policies such as indirect taxation of energy sources, and energy intensive commodities (such as steel, aluminum, or transportation), tariffs and quantity restrictions on oil and other imports, and various abatement strategies for emissions of GHGs and other pollutants, can, over a period of time for adjustment, have profound impacts on energy use efficiencies, patterns of use of different energy types, and the environment.

National level policies include fiscal incentives for greater energy use efficiency in the economy as a whole including the transportation, industrial and utility sectors. Market incentives for creation of offsets, including tradeable offsets of new sources of GHGs such as forest plantations, constitute another set. A third set are industry or economy wide emissions standards, maintained by flat or by marketable permits, possibly including trading permits with offsets.

The category of fiscal incentives for greater energy efficiency would, typically, include indirect taxation of energy sources, as well as taxation of inefficient use of energy in the transportation sector, while subsidizing more (technically) efficient energy use, for example, public transportation. Similarly, shifts to alternative technically feasible fuel types, which generate lower quantities of GHGs or other pollutants, such as renewable energy sources, may be motivated by differential taxes, such as a `GHGs tax'[ii], or subsidies on different fuel types. Other fiscal strategies, for example indirect taxation of energy intensive sectors, such as steel or aluminium manufacture, may have the effect of significantly reducing overall energy consumption. In the economy, and perhaps on energy use efficiency and pollution generated, by motivating such industries to reduce energy use by substituting other inputs for energy. Such instruments may also be selectively applied on sectors, in which substitution possibilities are the highest. Alternatively, such taxation may result in increases relative prices for these commodities, which in turn may result in reduced demand and output, and shift in investment to less energy intensive industries, with a consequent fall in energy use.

Offsets for emissions of GHGs are intended to furnish compensatory capacity to the ecosystem for removal of GHGs from the ecosystem. Importantly, these would include forest plantations, with the safeguard that the bio-mass generated would not be used as fuel. While forests remove only carbon dioxide, to the proportional extent that other GHGs are fungible with CO_2 in their greenhouse impact, their emissions too may be compensated for by forest plantations. Further, industries generating GHGs, and under obligation to compensate such emissions, may do so by renting offset capacity in national or international markets from other agents. The income redistribute effects of such offset schemes, between the factors in which GHGs generating sectors are intensive, typically capital, and those in which the offset sector is intensive, land and rural labour, are important from the policy standpoint.

Direct regulatory devices for environmental regulation have traditionally included emissions standards, as well as pollution taxes (or fees), and subsidies for reducing pollution. The standard results relied upon for operating these policy instruments have evolved mostly through partial equilibrium (PE) analyses, since theoretical general equilibrium (GE) analyses in this field have been emerging more recently (Boero et al., 1991). These results assume that effective enforcement is possible and costless. On the other hand, it is well understood by economists that `almost anything can happen in a general equilibrium model, under particular assumptions about factor proportions and elasticities' (Hartwick and Olewiler, (1986, p 414). It would accordingly be inadvisable to assume that the results presented below apply unchanged in the GE situation as well:

1. A government trying to achieve an optimal amount of pollution through the use of taxes or fees that reflect individuals willingness to pay for pollution reduction will have difficulty determining the optimal tax. This is because of the `free-rider' problem: when the tax or fee is an increasing function of the individuals stated willingness to pay, it is a dominant strategy for individuals to always under-report willingness to pay for pollution reduction, and the level of pollution resulting from the use of taxes or fees determined on the basis of such revelations will be more than is optimal.[iii]

2. In a consumption externality such as that involving air-pollution, property rights and the initial position for bargaining over emissions levels will affect the final equilibrium. The amount of air-pollution that exists after the externality is internalized is typically higher if initially the air is polluted and polluters have the right to use the air as a waste depository, than if clean air is the starting point and pollution is not permitted initially.

3. The imposition of a tax on pollution can internalize an externality, and achieve allocative efficiency. However, if real incomes are to be maintained at pre-tax levels, those facing the tax must be subsidized. When the marginal costs of abatement of pollution differ among firms, a tax minimizes the total costs of abatement for any given environmental quality standard.[iv]

4. Emissions standards (quantity restrictions) on pollution can also internalize the externality, but typically entail higher enforcement costs than an optimal tax. When the marginal costs of abating pollution differ among firms, a standard will entail higher costs of abatement than a tax which accomplishes the same level of environmental quality.

5. A production externality that leads to pollution is internalized where the marginal benefits from pollution equal the marginal damages from pollution. The optimal amount of pollution is generally not equal to zero. If the externality is private, merger and bargaining can internalize it. If the externality is public, taxes and/or standards are required.

6.A subsidy to firms to reduce pollution, will in the long-run, lead to increased entry into the polluting industry, and lead to increase in pollution over time. An equivalent tax will lead to exit from the industry, and reduce aggregate pollution.

7.When the government does not know the location of the marginal benefit or damage curves for pollution, but has information on their slopes, it should use a pollution standard if the marginal benefit curve is flatter (in absolute value) than the marginal damage curve, and a tax if the reverse is true. This will minimize the expected efficiency losses from adopting a non-optimal policy.

In addition to the policy instruments discussed above, tradeable permits[v] have been proposed by economists as a means of achieving aggregate pollution standards at potentially lower cost than standards imposed on each polluter. Some proposed systems are;

1.The Ambient Based System (ABS) which requires polluters to hold permits for all regions into which their emissions flow. The government determines the aggregate number of permits consistent with the ambient air quality for each region, assigns or auctions the permits to polluters, and allows them to trade. The market price of the permits is then the marginal abatement cost for the marginal firm in each region.

2.The Emissions Based System (EBS), defines the number of permits for a given region consistent with a desired regional standard, without reference to any local variation within the region (`hot spots'). Polluters can trade only within the region and all emissions within a given regional are treated as equivalent.

3.The Offset System, relies on tradeable permits defined in terms of emissions within the region, as long as air quality is maintained at all receptor points.[vi] One market operates for each region (like the EBS). Cost minimization trade would result given a sufficient number of participants.[vii]

While emissions standards are essentially command instruments, pollution taxes, emissions trading and tradeable permits are incentive based. Additionally, tradeable permits also eliminate uncertainty about aggregate economy wide emissions levels, and in the case of auctioned permits, the need to determine initial emissions endowments, assuming that the policy is effectively administered. However, emissions standards may be administratively simpler to operate, particularly if enforced through technology approvals.[viii]

All of these policy devices may be employed by national governments for regulating GHGs emissions. Some considerations which are specific to the case of GHGs regulation, both national and multilateral, and which should be kept in mind while considering the application of these instruments, are as follows:

1. While the damage from climate change may be uneven between global regions, the emissions from all points on the globe are equivalent in their damage potential wherever they may occur (Gottinger and Barnes, 1993). This is because GHGs are rapidly dispensed in the atmosphere, while their impacts on global climate may take decades to manifest. This means that it is only necessary to ensure that global limits on net emissions of GHGs are maintained, and actual net emissions from different countries or regions may vary. Thus, trading in emissions rights may be organized at different levels: national, regional, and global, without regard to local variations in climatic impacts.

2. For any given country, the marginal damage curve is highly uncertain at the present state of knowledge regarding the impacts of global climate change. Almost any assumption regarding the slope of the marginal damage curve for a particular country: flat, downward sloping, or upward sloping may be argued without categorical refutation. It is even possible that some countries may experience zero or negative marginal damage curves. Further while the marginal benefits curves are plausibly always in the positive region, their slope too are highly uncertain in most cases. Devising optimal policies, for example, levels of

standards or taxes, depend on knowledge of these curves. An illustrator is furnished for the cases of standards and taxes in Figures 1 and 2. First best policies for GHGs regulation from the efficiency standpoint cannot therefore be identified in general, at the level of individual countries.

Figure 1:Efficiency Losses due to Uncertainty in Marginal Benefit Curve (Graphical PE Analysis)

t: Pollution tax, Z: standard
MB: True marginal benefit curve
MB': Mistaken marginal benefit curve
MD: Marginal damage curve

Area abc: Efficiency loss due to standards
Area bed: Efficiency loss due to pollution tax

Figure 2:Efficiency Losses due to Uncertainty in Marginal Damage Curve (Graphical PE Analysis)

t: Pollution tax, Z': standard
MD: True marginal damage curve
MD': Mistaken marginal damage curve

Area abc: Efficiency loss when either standards or pollution taxes are used.

3. Since the major source of GHGs emissions is energy use by industries, and almost all industries employ significant energy inputs, the use of GHGs regulatory (and fiscal policy) instruments will significantly affect energy use patterns. Second order effects will be pervasive, and cannot be captured by PE analyses, on the results of which policy recommendations are typically based. Since few theoretical GE analyses have been attempted, policies may be based on empirical GE approaches. This is true at both national and multilateral levels.

The present modelling exercise allows, at the national level, for emissions standards, tradeable permits (both assigned and auctioned), taxes, and trading in offsets. The question of which particular instruments will be chosen may reflect the historical experience, administrative structure, and political culture of each country.

Perceptions of how well the instruments are believed to work, can matter a great deal for instrument choice, for example, in the adoption of market-based incentives (Heister et al., 1992). Additionally, information transmission across countries is also important in explaining what problems get regulated, and the type of regulations adopted. While there is wide agreement among economists that the presumption of government policies being economically efficient are unwarranted, little is known about the extent of deviation from economic efficiency that results from government policies.

3.2 Multilateral Policy Instruments

A long-term solution to the global problem of GHGs emissions will require a multilateral agreement on overall net emissions criteria for apportionment of emissions rights between countries and verification provisions. While one can state with certainty that such an agreement must provide for independent national procedures for compliance, little else can be stated with confidence in present regarding other possible terms.

The action of tradeable permits by some internationally authorized body to sovereign states is probably infeasible in the multilateral context. This is because INCs with greater resources will be perceived to have the ability to form buyer cartels at such auctions, to the detriment of developing countries (DCs) which have fewer resources, and are more numerous and heterogenous. Even if such a market were competitive, equity considerations would preclude assigning emissions rights to countries on the basis of existing national incomes (or national stock of marketable goods and services). Further, the disbursement of revenues collected through such auctions would involve major international political problems.

The Montreal Protocol (1988) on potential ozone depletion (POD) emissions is the sole precedent of an international agreement on a long-term, global atmospheric pollution problem. The international regulatory system included in the present model, is derived from certain features of the Montreal Protocol on which no serious objections have yet been expressed, even though the Protocol as a whole has not been accepted by a majority of states in the UN system.

The original signatories to the Protocol numbered 25 States, including the US, the former USSR and the European Economic Community members. No major developing country, including China and India, acceded. At a conference in London in March 1989, these two countries spelled out their objections to the original Protocol. China objected to asymmetrical treatment of industrialized and developing countries on the question of quota assignments stating that the document did not fully reflect the fair rule of `the greater the emission, the greater the reduction'. In particular the base levels for determining future consumption and production were centered on the existing low levels and therefore perceived as inequitable to DCs. India's objections to the Protocol also centered on unequal assignments of consumption quotas between industrialized and developing countries. It was pointed out that, in practical terms because of the existing extremely low present levels of consumption of the controlled substances in the DCs even the upper limit of 0.3 kg per capita per year during 1995-97 was irrelevant. The Protocol would have the long term result of allowing consumption levels of only 0.005 kg per capita per year for developing countries, compared to 100 times that level per capita year for INCs. Further, India felt that the provisions for assistance to developing countries to enable them to switch to environmental benign technologies were vague, and that such assistance should be reflected in the Protocol as a manifestation of a mandatory `polluter pays' principle.

To date 53 countries (out of 166 in the UN system) have committed themselves to acceding to the Protocol. The majority of those who have not acceded are developing countries. Clearly, the objections to the Protocol articulated by China and India are shared by many DCs. However, one may identify aspects of the Protocol about which no serious reservations have been expressed, and regarding which it may be assumed that there is international consensus. The international regulatory system for GHGs postulated in the model here is fashioned after these aspects.

First, the idea of international regulation of ozone depletors as a global environmental problem, including verification and penalty provisions, has not been objected to by any sovereign State. By analogy, it is postulated that the idea of some international regulatory regime for GHGs is acceptable to the international community. Further, as stated above, the Villach-Bellagio and Toronto conferences called for examination of a global convention as a framework for specific Protocols for atmospheric pollution. Second, the concept of mandatory national (production and consumption) quotas for PODs within such a Protocol, as distinct from the question of the basis for allotment of such quotas, has not been objected to by potential signatory States. Third, no objections have been voiced on the concept of trading in (production) quotas for PODs by signatories, and of fungibility between different controlled substances within overall environmental damage limitations (in production and consumption) allowed to each State.

The international regulatory regime postulated in the present model derives from these generally acceptable features of the Montreal Protocol. In brief, it includes net national emissions quotas for GHGs (with fungibility between different GHGs and offsets based on their greenhouse potential) and trading in net national emissions quotas. The economic effects of actual level of net national emissions quotas and financial flows between signatory States linked to past emissions (an application of the `polluter pays' principle), which are two controversial aspects of the Montreal Protocol, may be explored through simulations of the model.

The multilateral instruments which are particularly important in the

GHGs context, are international trading in national GHGs quotas and offsets and financial flows linked to past emissions. Trading in GHGs entitlements and offsets may permit the achievement of agreed standards at lower overall resource cost than non-transferable net emissions quota assignments. Net national emissions quotas, being tradeable, and financial flows would represent real resource endowments, and countries may be expected to agitate strongly by allotment schemes that would ensure for them the largest share of such endowments. An important objective of the present modelling effort, is thus, to fashion a policy analysis tool that would help countries develop their negotiating positions over national emissions quotas, and financial flows linked to past emissions, in the light of their perceived national interests. In case `free-riding' would not be a problem such interests point toward *joint implementation* schemes. (Hanisch et al., 1993). Other objectives include evaluation of the impacts on the national economy of different domestic policy instruments for reduction in GHGs emissions.

4 CONCLUSIONS

Climate change due to emissions of greenhouse gases is a long-term, global environmental problem. While specific impacts on different regions as well as their timing, are yet uncertain. It is reasonable to suppose that unilateral voluntary action by individual countries to reduce their net emissions of GHGs is unlikely. This is because significant reduction of net GHGs emissions by a single major net omitter, say for example the US is unlikely to substantially slow down their rate of increase in concentration in the atmosphere[ix] because the emissions of GHGs worldwide is increasing rapidly with spreading industrialization. On the other hand, unilateral changes in energy use patterns are widely perceived to have adverse effects on a country's economic growth consumer welfare, and trade competitiveness. This perception is shared by both developing (DCs) and industrialized countries (INCs).

It is likely therefore, that if the scientific evidence for major adverse environmental impact of global net emissions of GHGs becomes strong, negotiations for an eventual international treaty to limit or reduce net GHGs emissions would gain momentum. Countries would be hardly likely, however, to relinquish their independence in the matter of domestic control over policies for compliance with the negotiated terms of such a protocol, in favour of a supranational regulatory body. This would be due to considerations of preserving national sovereignty, as well as the belief that the choice of domestic policies for national compliance with such a multilateral scheme may have important growth, welfare distributive, and trade impacts. The question of instrument choice for regulation of net GHGs emissions at the national level, is therefore important from the policy perspective.

Significant changes in net GHGs emissions in any country will have to focus on energy use patterns, as well as on afforestation. This is because the most important of GHGs which result from anthropogenic activities, CO_2 and another GHG, N_2O, largely result from fossil fuel use. Further, the major offset to GHGs (since on the issue of climate change, different GHGs are fungible in their damage potential) is forests which sequester carbon from CO_2. Thus regulation of net GHGs emissions is also related to the use of land, an important natural resource and primary factor input.

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Footnotes

i. Source: Statement issued by the participants at the World Conference on `The Changing Atmosphere: Implications for Global Security', June 1988, reproduced in Boyle and Ardill, (1989), pp. 247-257.

ii. A GHGs tax is a tax on net emissions of CO_2 or other GHGs in terms of their damage potential.

iii. A theoretical solution to the free-rider problem has been proposed by Groves and Ledyard (1977). This approach presents a general equilibrium model in which private commodities are allocated through competitive markets and public goods by government allocation and taxation rules that depend on information communicated to the government by consumers regarding their preferences. A wide range of strategic behaviour, including the possibility of understatement of preferences or free-riding, is allowed for consumers in their communication with the government. The paper formulates a particular government allocation-taxation scheme for which the behavioral equilibria are Pareto optimal: given the government rules, consumers find it in their self-interest to reveal their true preferences for public goods. No real world scheme has yet evolved or been proposed as a practical manifestation of these results since budget balance for the government cannot be guaranteed under their proposed mechanism, and indeed, the authors acknowledge that it is impractical to directly implement their proposed scheme.

iv. The government does not need to know the costs of abatement, nor does the tax have to be optimally chosen. Formally, the planner's problem is to minimize the sum of expenditures over all firms on two kinds of inputs: those used to control pollution, and those used to produce conventional goods, subject to restrictions on pollution, production, and on the relationship between pollution and production.

v. Each permit applies to a `single' pollutant defined in terms of the type of environmental damage caused. Thus, in the case of GHGs, permits may be designed for emissions of CO_2 and N_2O together each weighted by its greenhouse effect potential.

vi. Receptor points are locations where air or water quality is measured, and where it is desired by policy to maintain environmental quality.

vii. The model described below, allows for tradeable permits, analogous to EBS, for both domestic and international regulation of GHGs.

viii. Some experience in the operation of emissions trading between firms, perhaps a precursor of tradeable permits, has been gained in the US since 1976. One assessment is that the scheme has saved more than $4 billion in control costs, with no adverse impact on air quality (Hahn and Hester, 1987).

ix. The US in the eighties contributed one quarter of world wide emissions of CO_2, the most important of GHGs (Gottinger and Barnes, 1993).