What Does Stabilizing Greenhouse Gas Concentrations Mean?

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The MIT Emissions Prediction and Policy Analysis (EPPA) model is applied to an exploration of the national emissions obligations that would be required to stabilize atmospheric CO_2 concentrations at levels now under active discussion. The results indicate that the needed voluntary participation will be difficult to achieve, not least because nations at very different income levels would have to undertake similarly costly emissions restrictions. The need for more attention to the linkage between short-term policy proposals and long-term stabilization goals is highlighted.

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Because key natural processes involved in climate change operate over periods on the order of a century, the science of climate change compels attention to time-scales that are longer than those usually considered in policy analysis. The longevity of assets employed in the production and consumption of energy reinforce that compulsion. Article 2 of the Framework Convention on Climate Change (FCCC) asserts a policy objective that also requires attention to the long run:

> The ultimate objective of this Convention … is to achieve … stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. (United Nations, 1992)

In its second assessment report, the Intergovernmental Panel on Climate Change (IPCC) presented time-paths for global anthropogenic emissions of carbon dioxide (CO_2) that would stabilize atmospheric concentrations of that gas at levels ranging between 350 and 750 parts per million (ppm) by around the year 2100 (IPCC, 1996b). Several parties to the FCCC, including the European Union (EU), have proposed that, "…concentrations lower than 550 ppm should guide limitation and reduction efforts" (AGBM, 1996a, para. 41).

In order to stabilize atmospheric concentrations of greenhouse gases, individual nations will need to control their emissions over the next century and beyond. No nation has yet assumed or

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even proposed obligations of this duration, however. At present, industrialized nations who have signed the Climate Convention have agreed to attempt to return their emissions of greenhouse gases to 1990 levels by the year 2000. No developing countries have accepted any obligations to control emissions, and no nation has accepted any obligations beyond the year 2000.

This essay considers what sorts of national emissions control obligations would be required to stabilize atmospheric concentrations of CO_2 using emissions trajectories that are under active discussion. Our findings indicate that it will be difficult to induce the level of voluntary participation necessary to achieve these ambitious goals. Stabilization at 550 ppm, on which our analysis focuses, requires greater reductions in global emissions late in the next century than rich nations can physically manage by themselves. Trading (or effective joint implementation) would be necessary to achieve such goals. More importantly, nations that are poor relative to the OECD would have to voluntarily assume significant emissions reduction obligations in order to stabilize greenhouse gas concentrations.

A glimpse of the difficulties to be elaborated below can be seen in one simple picture, which suggests the level of effort that would be required to meet the kind of stabilization objectives being discussed.[1] On its vertical axis, Figure 1 shows the current (1990) carbon emissions per capita for four regional groupings. The regions shown are defined in Table 1: they are aggregations of a 12-region breakdown that is implemented in the analytical model (discussed below) that we use to analyze various policy choices. As shown in the table, nations within Annex I to the Framework Convention (United Nations, 1992) are divided into two groups: the OECD countries as of 1990, and an "Other Annex I" group including the Former Soviet Union and Central and Eastern Europe.[2] The non-Annex I countries are similarly divided into two groups, "Early" and "Later," according to how soon they might be in a position to shoulder some of the burdens of emissions restriction. (This division is discussed further below.)

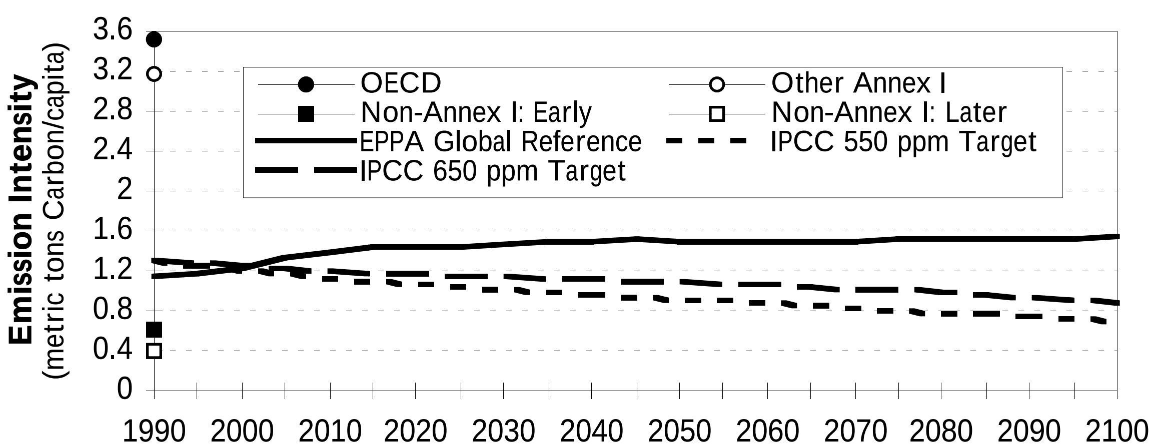

Figure 1. Per-capita carbon intensity in 1990 for four world regions, and global intensities needed to meet selected targets for atmospheric concentration.

[1] We owe the idea for this picture to Bert Bolin, who has employed a similar figure in oral presentations.

[2] Under Article 4.6 of the Climate Convention, parties included in Annex I undergoing the process of transition to a market economy were to be allowed, "a certain degree of flexibility in the implementation of their commitments."

Table 1. Regional grouping for viewing results.

OECD[†]: USA, European Community, Japan, Other OECD
Other Annex I: Former Soviet Union, Central and Eastern Europe
Non-Annex I: **Early**: Dynamic Asian Economies, China, Brazil
Non-Annex I: **Later**: India, Energy Exporting Countries[‡], Rest of World

[†] Our definition is for the OECD as of the early 1990s. Thus the European Community includes the 12 members as of that time, and the other OECD comprises Canada, Australia, New Zealand, EFTA (excluding Switzerland and Iceland), and Turkey.

[‡] Includes OPEC countries as well as a number of (generally low-income) oil, gas, and coal exporting countries (Burniaux, *et al*., 1992b).

The key fact is that, as aggregated in Figure 1, the 1990 per capita emissions of Annex I countries are five to ten times those of the non-Annex I countries. If we looked at individual countries, of course, the disparity would be even greater. In the USA, for example, emissions total 5.6 metric tons per capita, while per capita emissions in India amount to only 200 kilograms.

Figure 1 also shows the global CO_2 emissions per capita under the Reference Case scenario (described below), on which our analysis of alternative policies is based. For most of the next century, this scenario shows a slow rise in emissions. The effects of economic development are largely offset by a decline in the carbon intensity of GDP, which results from a combination of conservation and substitution toward low-carbon energy sources. What is more impressive are the emissions trajectories, on a global per capita basis, which must be met in order to achieve atmospheric stabilization at various levels. Two commonly discussed targets, 550 and 650 ppm CO_2, are plotted here, using the emissions trajectories developed in the Second Assessment Report of the IPCC (1996a).[3] If the world is to be on a trajectory to 550 ppm using the IPCC path, global per capita emissions can never be more than one quarter of the OECD level today. Indeed, they can never be much above the current levels of those regions that we classify as "Non-Annex I: Early."

The issues of equity in the distribution of burdens, and the extreme importance of attaining the cheapest possible schemes for emissions reduction, are evident at a glance, as is the great difficulty that lies ahead if these targets are to be taken seriously.[4] What follows is an elaboration of these aspects of what stabilizing concentrations might mean.

Analysis Methods

The MIT EPPA Model

To explore the implications of alternative policies leading to atmospheric stabilization, we apply the MIT Emissions Prediction and Policy Analysis (EPPA) Model (Yang, *et al*., 1996). EPPA has been derived from the General Equilibrium Environmental (GREEN) Model developed by the OECD (Burniaux, *et al*., 1992a). It describes the global economy as an interconnected set of national and regional entities, each with supplies of input factors (*e.g.*, labor, capital, land and other resources), consumer demand functions, and production technologies. By providing inputs

[3] These are the so-called S-series trajectories. The alternative timepaths developed by Wigley, *et al.*, (1996) are higher at first and lower after mid-century. For concreteness, this analysis concentrates on the 550 ppm trajectory.

[4] For other explorations of distributional issues, see Edmonds, *et al*. (1995), and Manne and Richels (1995).

to the production process, consumers earn the income to purchase final goods, and the circular flow of income and expenditure in such a model is captured in a simplified version of a national accounting system.

An EPPA-type model is referred to as a recursive-dynamic computable general equilibrium (CGE) model. It is said to model a "general equilibrium" because it finds a set of product and factor prices that balance supplies and demands in all markets in each period. The term "recursive" refers to the fact that the model is solved by stepping forward in time, with no influence of expected future changes in relative prices, or the imposition of new constraints. It is "dynamic" in the sense that the capital stocks in any period are, in part, an inheritance from previous periods. All goods are traded among regions. With the exception of two of these, imported goods are imperfect substitutes for the equivalent domestic ones, and goods imported from alternative foreign regions are imperfect substitutes for one another. The two exceptions are crude oil and natural gas: imported and domestic supplies of each are treated as perfect substitutes.

The model covers the period from 1985 to 2100 in five-year steps. Further, it represents the economic structure of each of its 12 regions in terms of eight fully-elaborated production sectors. Three of these are non-energy sectors (agriculture, energy-intensive industries, and other industries and services), and five are components of energy production (crude oil, natural gas, refined oil, coal, and electricity). There are four consumption sectors, plus a government sector and an investment sector.

The version of the model used here also incorporates two potential future energy supply or "backstop" production sectors, represented as Leontief functions of their inputs of labor and capital. One of the sectors represents an industry that uses heavy oils, tar sands, or oil shale to produce a perfect substitute for refined oil. Because of extensive processing requirements, substantial CO_2 is emitted in the production of these carbon-intensive fuels as well as in their consumption. The other backstop sector is a carbon-free electricity source, which represents the possible expansion of technologies like advanced nuclear and solar power.

The carbon-free electric backstop is available in all regions. However, the carbon-liquids backstop is assumed to be produced in only three regions that are known to have substantial amounts of the necessary resources: the Energy Exporting Countries (*e.g.*, Venezuelan tars and heavy oils), the Other OECD (*e.g.*, Canadian and Australian tar sands) and the United States (*e.g.*, Western oil shales). The location of this carbon-liquids potential will prove important in interpreting the results below.

The major driving factors in the model are population change, the rate of (labor) productivity growth, and a rate of Autonomous Energy Efficiency Improvement (AEEI), which reflects the effect of non-price-driven technical change on the energy intensity of economic activity. Another important influence on economic growth, the rate of capital formation, is endogenous to the model. Finally, a key determinant of the carbon intensity of economic growth, which also has an important influence on the distribution of burdens of a policy of CO_2 emissions restriction, is the assumed costs of the backstop technologies relative to conventional sources. Jacoby, *et al.* (1996), explore the uncertainty in these key parameters, and their influence on the resulting emissions predictions.

In this analysis we do not allow for the creation of any sort of world government. We accordingly assume that the only way that atmospheric stabilization can be achieved is by individual regions or blocks of regions (*e.g.*, the OECD) coming to voluntary agreement on CO_2 emission quotas. In some of the cases studied these quotas are considered to be tradable among regions. Restrictions on CO_2 emissions serve to depress the demand for output from the more carbon-intensive energy sectors and shift economic equilibria away from the no-policy baseline. The adjustments involved in these shifts are complex and may include substitution among fuels; substitution in production among factor inputs; changes in the mix of goods consumed; and shifts in international trade, both in energy and non-energy goods. These adjustments to emission constraints generally result in reductions in GDP and consumption levels. To summarize the costs of emissions restraints, we use a measure of economic welfare that is related to aggregate consumption within a region, aggregated to the four regional groupings shown in Table 1.

The Reference Case

The costs in achieving a stabilization goal, and the distribution of these burdens among world regions for any particular policy, depend on how large carbon emissions might be in the absence of any policy restraint. Thus the assessment of costs and burdens, or in some cases even physical feasibility, is a function of the prediction used as a reference case with no policy. On the time scales employed here, such predictions are necessarily highly uncertain (Jacoby, *et al*., 1996). Nonetheless, we pick a single reference (no policy) case, and compare various policy cases against it. Our purpose is not to show what must happen but to examine what can happen—and thus what should be allowed for in policy design.

Further, we compare various approaches to stabilization with the no-policy baseline as if each were followed to 2100 with no learning about costs or benefits and thus no adaptation in policy over time. This "policy scenario" construction gives limited guidance as to what should be done *today*, given that learning and subsequent adaptation are likely. But it does allow exploration of the types of issues that any policy design will have to confront over time, whatever baseline emissions trajectory ultimately reveals itself and whatever the globally optimal emissions trajectory is ultimately determined to be.

Table 2 shows the per capita GDP levels, in 1985 U.S. dollars, that are produced by the EPPA model, given our assumptions about population growth, rates of labor productivity growth, and other driving factors. Per-capita living standards in all regions grow dramatically over the next century. A comparison of this growth with the associated path of per-capita carbon emissions in Figure 1 will give a quick impression of the sharp decline in the carbon intensity of economic activity that is implicit in this reference case (for details, see Yang, *et al*., 1996).

Also to be seen in the table is the basis for classifying Non-Annex I countries as "Early" *vs*. "Later" in their likely ability and/or willingness to voluntarily assume some burdens of CO_2 control. In the analysis below we hypothesize that countries might begin to bear significant costs when they reach an average income level equal to one-half the level of the European Community in

Table 2. GDP[†] per capita for selected periods under the EPPA reference case.

	1990	**2010**	**2050**	**2100**
OECD	13.0	19.0	31.1	50.2
Other Annex I	2.9	5.6	9.2	18.3
Annex I: Early	1.3	2.5	6.7	11.9
Annex I: Later	1.2	1.8	2.6	3.6

[†] Gross Domestic Product in 1000s of 1985 U.S. dollars.

the early to mid-1990s, roughly the level of Portugal today (World Bank, 1996, Table 1). The regions making up the "Early" group achieve this status at different points in time, but all attain it by the middle part of the century. Given the current levels of GDP, and our assumed growth rates over time, the regions in the "Later" group do not reach this average level of GDP per capita by the end of the century.

There is much uncertainty about growth over such long periods, and a wide dispersion in economic performance is to be expected, so we may be wrong about which nations will turn out to be in which group. Other than adjustments for near-term fluctuations (such as the crash and eventual re-emergence of the Former Soviet Union and of Eastern and Central Europe), the economic growth shown in Table 2 is based on the assumption that rates of labor productivity growth will fall gradually over time, with the rates of change differing among regions. A simple algorithm is used that necessarily smoothes over the fluctuations that we know will come. Neither our model nor any other can reliably predict the emergence of a country or region whose economy booms over the course of several decades, as has been true of the Dynamic Asian Economies in the 1980s and 1990s. No model-based prediction from the vantage point of 1960 could have foreseen the last three decades of growth in China. What can be said with confidence is that some nations will experience high enough growth over long enough periods of time to be viewed as "rich enough" to bear some share of the effort needed to mitigate climate change, while others will remain "too poor" to bear such burdens. The distributional issues we highlight below are no less real for the fact that nobody can forecast exactly who will be in which position decade to decade. This fact simply points up the need for a climate policy architecture able to cope with surprises of this and other sorts (Schmalensee, 1996).

It is important to keep in mind that our four-group aggregation, and even the 12-region breakdown of the underlying EPPA model, obscures the considerable differences in circumstances that will exist *within* each region. For example, the Energy Exporting Countries is a diverse group that includes countries such as Kuwait and Saudi Arabia with high levels of GDP and carbon emissions per capita, along with large countries with high population growth rates and low initial levels of per capita income, such as Iran, Indonesia, Nigeria, and, Egypt. The equity issues revealed by our aggregate regional analysis would be magnified if they could be examined in detail at the national level.

In aggregate, anthropogenic CO_2 emissions in our reference case correspond closely to those implied by the IPCC's IS92a scenario. Global emissions in 2100 in the EPPA reference case are 18.3 GtC, compared with 19.8 GtC in IS92a (IPCC, 1992). Regional carbon emissions in our reference case are shown in Figure 2. In this scenario, with no policy restraint, the OECD maintains its position as the region with the largest emissions, although its share of the global total drops from 50% today to 40% in 2100. This reference case has a larger fraction of global carbon emissions in the OECD throughout the century, as compared to the IS92a scenario, which credits it with only 22% of emissions in 2100 (IPCC, 1992, Table A3.7).

In the EPPA model, differences among regions in economic growth and the evolution of carbon intensity arise not only from population and productivity growth rates but from the penetration of backstop technologies by region. Two of the three regions assumed to produce the carbon-fuels backstop are in the OECD, while the widespread availability assumed for the carbon-free electric backstop allows penetration of this non-carbon energy source in developing countries

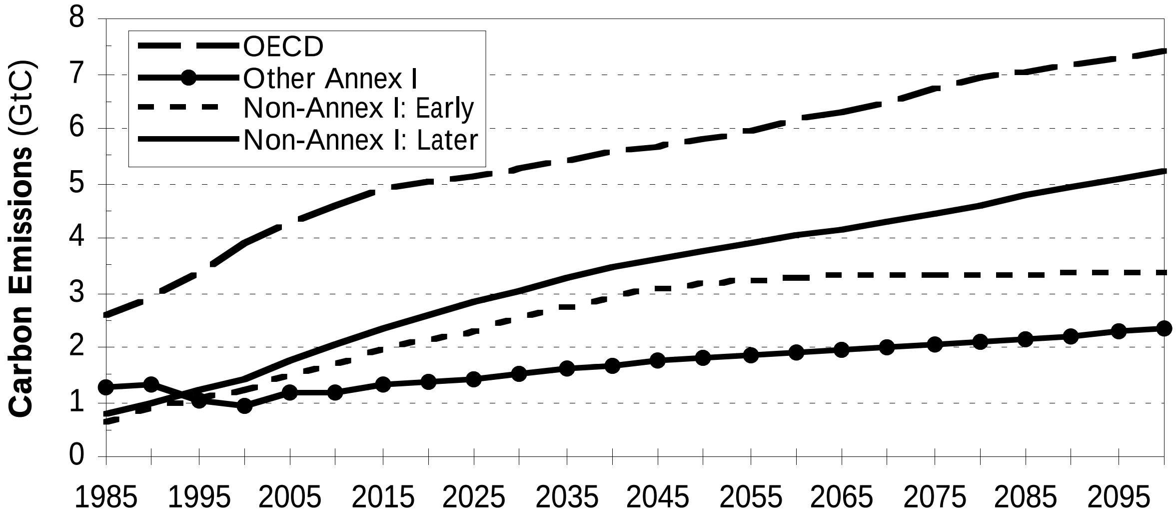

Figure 2. Regional carbon emissions under the EPPA reference case.

that have the greatest demand for new capacity. Coupled with relatively slow population growth rates, penetration of such a clean backstop helps to explain why carbon emissions in "Non-Annex I: Early," which rise rapidly with economic development in the first few decades of the analysis, are projected to stabilize by mid-century. By contrast, the "Non-Annex I: Later" group is seen to have the second largest emissions for most of the period shown because the population in this region is very large and is projected to grow rapidly relative to other regions. As in the OECD, this region produces the relatively dirty carbon fuels backstop, which results in a significant amount of emissions being attributed to the point of production. Finally, Figure 2 shows emissions from the "Other Annex I" nations growing relatively slowly after these countries complete their transitions to market economies.

Policy Regimes Leading to Stabilization

In order to explore the implications of proposals to stabilize atmospheric concentrations of greenhouse gases in the long run, we use as an example the 550 ppm target put forth by the European Union, as discussed above. There are many paths of global emissions that would lead to this atmospheric CO_2 concentration in some future century, but for purposes of this exercise we use the path calculated by the IPCC (1996a), which also lies behind Figure 1.

What general policy designs might be used in an attempt to achieve this restraint in global emissions growth? Clearly, it serves little to start down a path of significant control of these gases unless we have considered the kinds of political agreements and policy designs that will be needed to deal with possible events along the way. For such a long-term problem, what we do now ought to be consistent with some vision of the circumstances that may arise over that horizon. We should take particular care to avoid near-term policies that will raise the costs of actions likely to be necessary in the future, and we ought to push out the analytical horizon to explore these issues.

At present, the only general policy principle that has been widely accepted in the climate change arena is embodied in the Berlin Mandate (United Nations, 1995): Annex I nations alone should bear the costs of any emissions restrictions. We begin our analysis by examining whether this principle is consistent with the EU goal of stabilization at 550 ppm.

Restriction by Annex I Countries Only

Having the Annex I nations bear all the costs of the emissions reductions necessary to follow the IPCC 550 ppm path implies something like the following policy:

Policy 0: Annex I Only
Emissions follow the IPCC 550 ppm path. Non-Annex I regions are never constrained. Annex I regions abate (in proportion) as needed.

We calculate total Annex I emissions under this policy by simply subtracting baseline non-Annex I emissions from the IPCC total, assuming proportional abatement within the regions of Annex I. We consider an alternative regime below. One can treat the regional emissions that emerge from this calculation and those described below as either emissions ceilings in the absence of global trading or, with global trading, as year-by-year endowments of tradable emissions quotas. We explore both alternatives in what follows.

Figure 3 shows the regional emissions (or emissions quotas) implied by Policy 0. In order to follow the IPCC path in our baseline case, Annex I emissions must go negative late in the next century. This is, of course, physically impossible and means that in our baseline scenario, Policy 0 is not feasible. In scenarios with more rapid growth in non-Annex I emissions (including the IPCC's central IS92a scenario), the point at which Annex I emissions would go negative occurs earlier. Since global emissions decline rapidly and substantially after 2100 along the IPCC path, scenarios with slower non-Annex I emissions growth generally postpone this problem for only a relatively few years. One can imagine scenarios in which cheap, carbon-free technologies reduce emissions growth enough that "Annex I Only" is consistent in the long run with stabilization at 550 ppm, but it would clearly be unwise to bank on such a scenario being realized.

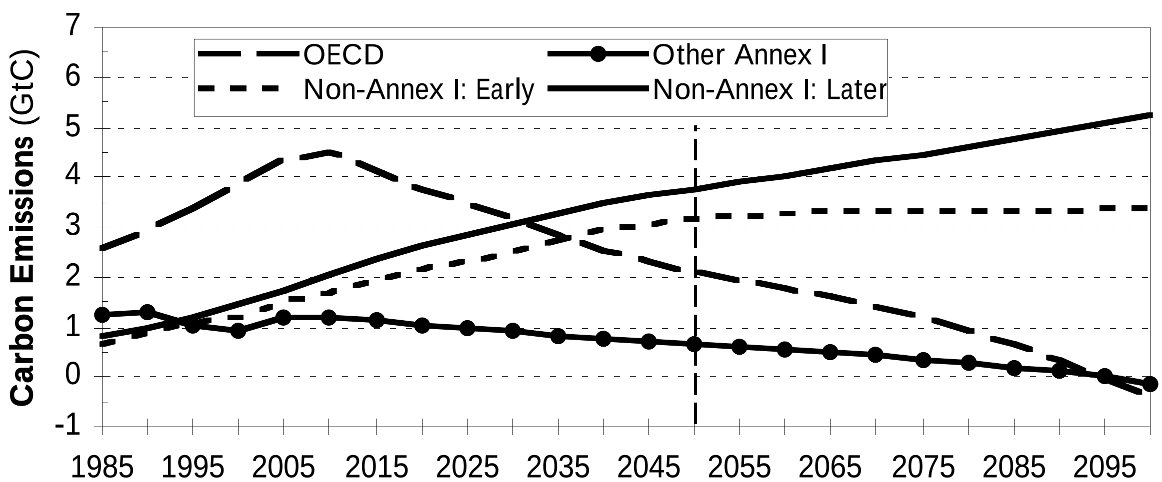

Figure 3. Regional carbon emissions under *Policy 0: Restriction by Annex I Regions Only*

It is interesting to look only at the part of Figure 3 to the left of the vertical dashed line. Doing so, limiting attention to the period before 2050, might suggest that a policy regime in which

Annex I alone bears abatement costs is worth considering for the long term. Recognizing that this regime is in fact not likely to be viable in the long term, however, one is forced to consider other regimes whose costs are more widely shared and, more importantly, to consider how a transition from "Annex I Only" might be brought about. At the very least it is important to ask whether adopting near-term "Annex I Only" emissions limits of the sort currently under discussion would hasten or retard the transition to a regime with broader international participation in burden-sharing.

Annex I Leads, Some Follow as Incomes Reach Critical Levels

One reaction to this finding, that stabilization at 550 ppm means that abatement costs must eventually be borne by at least some developing nations, could be to reject stabilization goals of this sort. If, however, stabilization is still found to be a desirable long-term goal, then it is also likely that the distribution of any emissions limitations among developing states will be a particularly thorny political issue both in North-South and South-South relations. The debate over burden-sharing schemes in this context is likely to dwarf in acrimony and complexity current discussions of "common but differentiated" responsibilities for emission reductions among Annex I states. For illustrative purposes, we will explore the implications of one notion of equity: above some minimum level of per-capita income, nations must begin to make contributions to emissions control. A simple implementation of this notion is the following:

Policy 1: Annex I Leads, Others Follow
Emissions follow the IPCC 550 ppm path. Each Non-Annex I region stabilizes when its GDP per capita reaches 50% of that of the EEC in 1995.[5] Annex I regions abate (in proportion) as needed.

The income level used to define Policy 1 is suggested by the inclusion of the relatively poor Southern European countries in Annex I. Under this regime, nations poorer than the OECD's current average would be asked to do something that the OECD has so far been unable or unwilling to do—and to incur the costs involved at a time when the OECD is much richer than it is today. We wonder whether this aspect of Policy 1 is likely to be accepted by enough non-Annex I states to produce the necessary emissions reductions.

Figure 4 shows the regional carbon emissions implied by Policy 1. Note that Annex I emissions are close to zero in the year 2100 along our baseline scenario, implying that this policy will not remain feasible for long thereafter. Nonetheless, it is instructive to analyze the consequences of this policy through the end of the next century.

Table 3 presents the net present values of the regional costs of this policy. All regions bear significant costs when emissions quotas cannot be traded; the non-Annex I regions are harmed by the reduction of their export sales to slower-growing Annex I states and, in some cases, by terms-of-trade effects. There are substantial gains in all regions from full global trade in emissions rights (although, as noted below, our model undoubtedly overstates the gains that could be realized in

[5] Here and below, contingent restrictions of this sort are applied at the level of the 12 regions in the EPPA model, and results are aggregated to the four regions defined in Table 1 for presentation purposes.

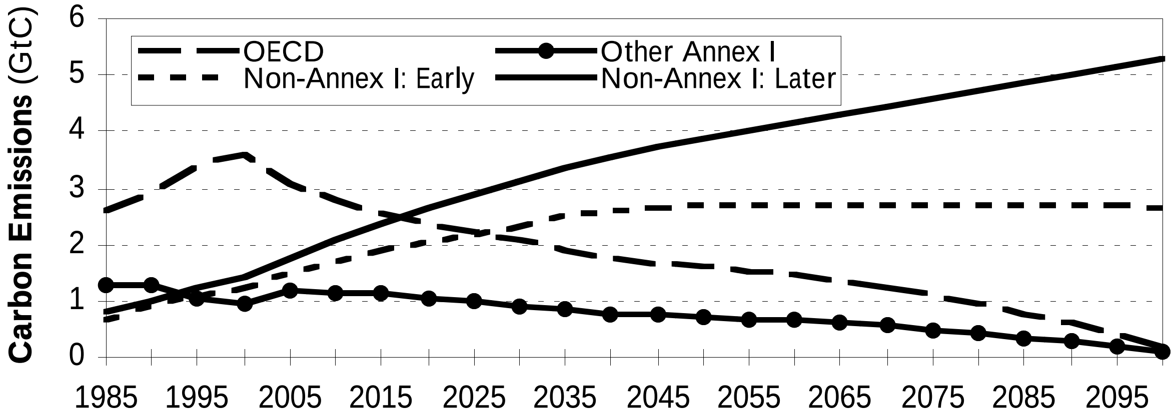

Figure 4. Regional carbon emissions under *Policy 1: Annex I Leads, Others Follow*.

Table 3. Regional percentage welfare losses for alternative policies, present value in 2000 of losses 2000 to 2100 discounted at 3%.

Policy	Regions			
	OECD	**Other Annex I**	**Non-Annex I: Early**	**Non-Annex I: Later**
1. Annex I Leads				
No Trade	5.20%	5.81%	1.55%	0.47%
With Trade	2.24%	4.76%	-0.05%	0.08%
2. OECD Leads				
No Trade	3.95%	3.85%	1.70%	0.70%
With Trade	2.05%	3.70%	0.29%	0.22%

practice). The ability to sell emissions rights to Annex I nations and use the proceeds to take advantage of low-cost domestic abatement opportunities eliminates almost all costs in non-Annex I regions.

Finally, note that the Other Annex I group bears a heavier burden than “Non-Annex I: Early,” particularly in the tradable case, even though, as Table 2 indicates, their average per capita incomes are comparable for much of the period. In the tradable case, “Other Annex I” bears a heavier relative burden than even the much richer OECD, and the reason is to be found in the relative costs of emissions restriction among regions. Although any region under restraint would seek to purchase permits from abroad, the OECD regions generally have a higher marginal cost of abatement, and thus they will be responsible for most of the purchases of emissions permits from (and transfers to) non-Annex I regions. “Other Annex I” regions are projected to have abatement costs (at least under the constraints imposed here) that are lower than in the OECD, but significantly higher than in the non-Annex I regions. Thus they are not candidates for transfers from OECD because they are subject to a similarly severe constraint, and they cannot afford to purchase sufficient carbon permits from non-Annex I regions to alleviate their economic burdens. Except in the first few decades, when carbon emissions are growing quickly in the “Early” regions, transfers are divided roughly 3:2 between “Non-Annex I: Later” and “Non-Annex I: Early.”

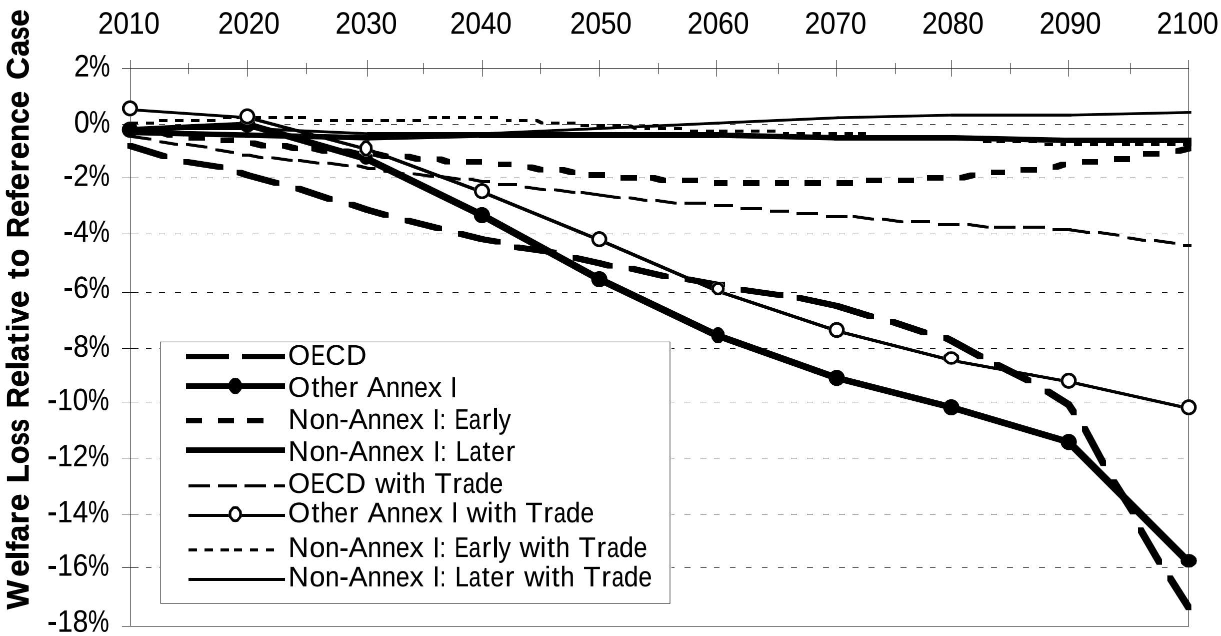

Figure 5. Welfare losses under *Policy 1: Annex I Leads,* with and without global trading.

Figure 5 provides the cost trajectories summarized in Table 3's present value measures. One cannot take too seriously the Annex I regions' no-trade losses late in the period: the levels of carbon emissions per dollar of GDP are well below anything that has been experienced or even seriously contemplated in an industrial economy, and beyond the region where the results from a model like EPPA are much to be trusted. Nonetheless, the steady increase in costs in the face of rapid technological advance, is likely to be robust. This feature has implications that are not suggested by summary present value statistics. It is simply not conceivable that the Former Soviet Union and the Central and Eastern European nations would voluntarily continue to bear rapidly rising emissions control costs that are disproportionately higher than those borne by other regions.

OECD Leads, Others Phase In as Incomes Reach Critical Levels

The discussion above suggests to us that a workable policy regime must ask less of the Other Annex I group of countries and also begin to explore finer distinctions among developing countries. To develop an illustrative policy of this sort, we simply treat all non-OECD regions alike. In order for this to be consistent with stabilization, more must then be asked of non-Annex I nations. Policy 2 is an exploration in this direction:

Policy 2: OECD Leads, Others Phase In (Emissions follow the IPCC 550 ppm path)

Non-OECD region obligations phase in as income rises as a percentage of 1995 EEC GDP per capita:

- Limit growth to 1% per year at 40%
- Stabilize emissions at 50%
- Reduce emissions at 0.4% per year at 100%

OECD regions abate (in proportion) as needed.

Policy 2 asks all non-OECD nations to limit emissions growth when their GDP per capita reaches 40% of the 1995 EEC level, to stabilize emissions when GDP per capita reaches 50% of that level, and to begin reducing emissions when GDP per capita matches the 1995 EEC level. We believe that this is asking a lot of non-OECD nations, at least relative to their so-far-expressed willingness to contribute, so we make no claims for political feasibility. Particularly contentious may be the lower threshold (40% of EEC level today) at which point limitations are placed on "Non-Annex I: Later" after 2050. As in the case of Policy 1, unconstrained growth in these regions will have the tendency to crowd out virtually all OECD emissions, so this relatively mild constraint on growth in emissions is necessary to prop up OECD emissions to levels that are severely constrained but conceivable. If efficient compensation mechanisms could be guaranteed then perhaps such constraints might not be necessary, since the OECD could then simply buy its way out of the severe constraints.

Figure 6 shows the regional carbon emissions (or emission quotas) implied by this policy. Note that OECD and "Other Annex I" emissions are significantly greater in 2100 than under Policy 1. Problems after the turn of the century seem likely however, since "Non-Annex I: Later" emissions continue to rise, other non-OECD emissions are at best gently declining, and aggregate emissions must drop sharply to follow the IPCC path.

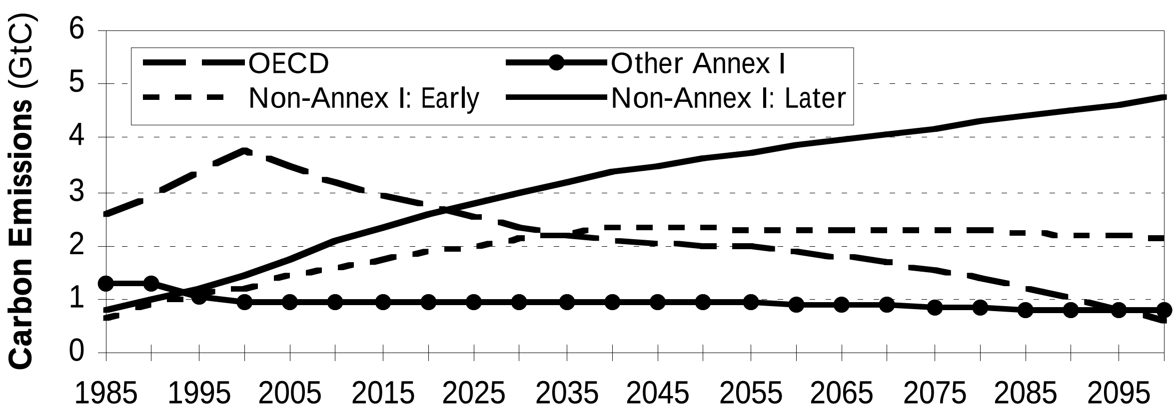

Figure 6. Regional carbon emissions under *Policy 2: OECD Leads, Others Phase In.*

Regional present value costs of this policy are given in Table 3. Consider first the non-tradable case. Costs have clearly been shifted from the two Annex I groups to the developing world. Note however, that "Other Annex I" still bears disproportionately high costs. The income-based burden-sharing rule in Policy 2 relates to carbon emissions, not abatement costs, and the costs of reducing emissions will vary substantially across nations—perhaps in the fashion described by our model, perhaps according to some other pattern.

The gains from trade are somewhat less under this policy than under Policy 1, particularly for "Other Annex I." Since emissions constraints are more widespread, there is less "low-hanging fruit" available for trading. Still, trading produces a significant relative reduction in the costs (already low in absolute terms) that are borne by non-Annex I nations. Under the tradable version of Policy 2, the "Later" regions still receive over half of the transfers while the "Early" regions still capture some 30%. Thus, even when included among the regions eligible for transfers, Other

Annex I still never receives more than 10 to 15% of total transfers because of the ordering of relative marginal abatement costs particular to this allocation of carbon permits. The relative penetration of backstops by region, the rate of removal of subsidies, and autonomous changes in energy efficiency over time, all of which are highly uncertain, are important drivers of these marginal abatement costs. The choice of similarly plausible but somewhat different values would dramatically affect the relative abatement costs and thus the regions that would benefit most from trading.

Finally, Figure 7 shows the cost trajectories under Policy 2 when emissions quotas are not tradable. (Because gains from trade are relatively small in this case, superimposing the tradable case, as in Figure 5, would mainly add clutter.) Note again that costs for both Annex I regions tend to increase over time, and the long-term political viability of this policy as it relates to the Former Soviet Union would seem to be doubtful.

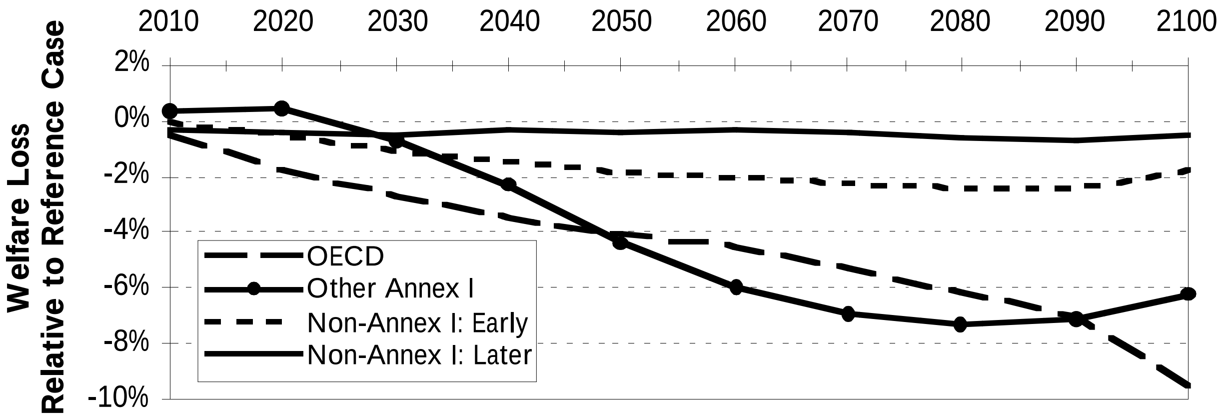

Figure 7. Welfare losses under *Policy 2: OECD Leads*, without global trading.

Concluding Observations

This essay is intended to start a conversation, not to end one. We are concerned that goals for the very long term are being discussed at the same time as very short-term emissions control policies, with insufficient attention to the linkages between them. In our view it is vitally important to consider the long run, if only because it may lead advocates of lofty long-run goals to feel obliged to describe policies that have at least some chance of being technically and politically feasible on time scales relevant to the problem. The EPPA model and the simulation experiments used here do not provide definitive measures of cost or feasibility, but they do call attention to several important issues at the nexus of the short and the long term.

First, the analysis above shows that tradable emissions quotas or some policy regime with similar effects will almost certainly be necessary both to lower the burden on Annex I (or OECD only) states, and simultaneously to encourage the non-Annex I states to take part in protocols that limit their emissions. Compensation mechanisms will be necessary for any such agreement to move forward, and the reductions that any protocol can reasonably demand of parties to an agreement (whether Annex I or non-Annex I) will be contingent on the particular mechanism envisaged. For example, the allocation of less than one gigaton in carbon emissions (approximately one-half of the *current* U.S. level alone) to the entire OECD in the latter half of the century, as implied in the "Annex I Leads" scenario, is utterly unrealistic unless something equivalent to a full global trading system in carbon permits is in place. And even though such a mechanism appears essential to significant emissions reduction, the prospect remains daunting. It is important to recall that economic models assume that trading occurs with no friction or transactions costs, and that it leads to lowest-cost allocation of global abatement. Since all real markets have costs and frictions, particularly markets that cross borders, our results overstate the benefits of trading to an unknown but possibly substantial degree.

Further, the question of crediting cannot simply be deferred indefinitely. If countries not subject to near-term restrictions are to fall under a control regime eventually, any trading scheme should provide the opportunity for those countries to "bank" credits by carrying out emissions reductions activities *before* they are subject to restraints. This concern arises in particular with regard to Joint Implementation projects carried out in developing countries and paid for by OECD nations. The sooner a mechanism to award credits is developed the less hesitant all states will be to begin to undertake projects to earn such credits.

Second is the issue of what would constitute "equitable" burden-sharing over the long term, keeping in mind that the ultimate test of fairness in the absence of a world government is the willingness of nations to bear the implied burdens voluntarily. Our analysis points up the importance of refining the concept of "common but differentiated" responsibilities to make it adaptable to changing circumstances. First steps in seeking a definition of this term have been taken by the Ad Hoc Group on the Berlin Mandate (AGBM, 1996b), as it struggles with widely divergent claims as to what would be an equitable set of indicators. Since a serious attempt to stabilize atmospheric concentrations of CO_2 is likely to require the assumption of responsibilities by non-Annex I nations, it is important to broaden the topic of these discussions beyond the differentiation within Annex I alone.

The threshold(s) used in our scenarios are based on per capita income. However, it may be that per capita income is not an adequate means by which to include or exclude a state from a control regime. If, for example, our illustrative threshold of half the 1995 EEC GDP per capita were indeed established, but late in the next century the major emitters of the developing world were found not to be approaching that level, then stabilization of atmospheric concentrations of CO_2 at levels currently under discussion would be unlikely. Other criteria can be imagined, of course. Perhaps aggregate emissions, or the share of global emissions, might be a more desirable criterion. More easily realizable, and perhaps the criteria most commonly discussed within Annex I, would be a criteria that would be based on carbon emissions per capita, *i.e.*, a population-based allocation.

One might also argue that rather than using GDP thresholds, like those in our policy cases, the control obligation should be tied *directly* to some indicator of economic well-being. Thus, countries might face a sliding scale of commitments based on the dynamics of their particular economic growth. A continuous scale would, however, be highly data-intensive and might encourage countries, which are the source of most economic data, to underreport economic growth (or carbon emissions). Such a system may thus be not as easily implemented as the thresholds proposed in our scenarios.

Alternatively, one might argue that Annex I should simply be expanded as countries and regions attain income levels comparable to that of the OECD. This argument implies that, in particular, Dynamic Asian Economies that have attained such income levels already, or will soon do so, should be incorporated into Annex I reasonably quickly. Reopening the issue of membership in Annex I would also provide the impetus to move countries of the Former Soviet Union and of Eastern and Central Europe out of Annex I and, perhaps, into some new intermediate category with fast-growing regions such as the Dynamic Asian Economies. Rather than having to re-open debate on such issues every time a country booms or a region collapses, the use of established criteria based on economic activity or greenhouse gas emissions would obviate the need for such potentially delicate negotiations as economic fortunes rise and fall, and as resources are depleted and new fuel sources or technologies emerge.

As this discussion illustrates, and as New Zealand suggested in a submission to the AGBM with reference to burden-sharing within Annex I, one can expect that, "…seeking agreement on apportioning responsibility (*e.g.*, on the basis of emissions per capita, per GDP or specific economic structures or fuel mixes) will rapidly lead towards special pleading on the grounds of individual national circumstances which are unlikely to be either testable or economically efficient" (AGBM, 1996b, p. 16).[6] It seems more likely that some sort of *ad hoc* compromise allocation of responsibilities will emerge from political bargaining than that any single principle of equity will be accepted and used to derive the ultimate allocation (Schmalensee, 1995). It is thus important to begin the process of developing institutions that can engage in such bargaining—and modify its results as economic and environmental surprises occur.

Finally, it should be clear from our analysis that the world would likely find it difficult to follow the IPCC path (or, we would argue, any other similar path) to stabilization of atmospheric concentrations of CO_2 at 550 ppm. Our baseline scenario may over-state or under-state the costs involved or the complexity of the equity issues that would be encountered, but we do not believe it gives a qualitatively misleading picture of either. Therefore, in the absence of any demonstrated threshold effects, and in light of the inability of today's governments to commit their successors to follow any long-term emissions trajectory, it is unclear how seriously stabilization of atmospheric concentrations of greenhouse gases should be taken as a policy goal. While our essay indicates how the concept may help lead analysts to think longer term, it is not clear that levels of atmospheric stabilization are the best device for defining the domain of international negotiations. And thus there is *much* more to be done in this area, even at the level of identifying the best structure within which to carry out the policy debate.

[6] A more detailed discussion of equity concerns and potential criteria can be found in Grubb (1995) and the IPCC Working Group III chapter on equity and social considerations (IPCC, 1996b).

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