TOWARD A USEFUL ARCHITECTURE FOR CLIMATE CHANGE NEGOTIATIONS

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1. INTRODUCTION

The policy problem posed by climate change is daunting. Absent evidence that climate change is not a risk to human and natural systems, the world faces an unending series of difficult international negotiations about measures to limit greenhouse gas emissions. To be successful, the resulting climate regime must be able to survive over many decades, adapting to changing economic conditions, to evolution in our understanding of how climate system works, and to both success and failure of subsidiary agreements along the way. Prospects for reaching rational, workable agreements will be increased if these negotiations are governed by a useful policy architecture: a unifying structure that restricts potential agreements in ways that both simplify negotiations and point them in substantively desirable directions. Sound constitutions are the most obvious examples of such architectures, but, as we discuss in Section 2, the notion is much broader.

Unfortunately, despite developments in the areas of emissions targets and nascent flexibility mechanisms, a fully useful policy architecture has not yet evolved from the climate negotiations. It is not clear how to move beyond the agreements reached in Kyoto, particularly considering the clear division that has been established between Annex I parties who have obligations for emissions control, and all other nations who do not. The issue of accession of Non-Annex I parties has been kept off the table, and there is neither a commonly accepted model of what accession and subsequent obligation would look like, nor even commonly accepted architectural principles to guide discussions of these issues. For example, if a Non-Annex I country were allowed to join in the existing structure of Kyoto emissions targets, what initial level of commitment would be appropriate? How would it relate to the commitments of the existing (and richer) Annex I parties? How should commitments evolve over time and in response to economic growth? Finally, how would these choices about accession and subsequent commitment play out in terms of the likely "adequacy" of the overall control effort in the face of an atmospheric target? Even though many nations may oppose the formal adoption of rules or guidelines for these issues, some structure and common language is needed even to allow coherent conversation.

Like the block of raw granite that has a statue inside, only awaiting the removal of the excess stone, the structure of current agreements may contain elements of an architecture for dealing with these difficult issues. In Sections 3 and 4 we discuss a class of architectures that we feel has the potential to be useful in this context, and in Section 5 we present the results of some illustrative calculations. We do not intend to suggest that this class, which stresses explicit consideration of ability to pay as a determinant of incremental emissions control obligations, is optimal in any meaningful sense. In particular, the cartoon architecture we analyze quantitatively in Section 5 is almost certainly too inflexible to serve as the focus of productive international negotiations. Our objective is more modest. Decisions made today will shape the policy architecture that, in turn, will shape future climate negotiations. We believe that the longer-run implications of those decisions deserve explicit attention, and that serious thought should be given to the climate policy architecture that we will bequeath to our children.1 If they need to reduce global emissions drastically, it will be tragic if we have not put in place a conceptual framework that eases their task.

2. USEFUL POLICY ARCHITECTURES

The meaning we intend to convey by the term “architecture” follows Schmalensee (1998), and it is close to its meaning in the software industry. Cusumano and Selby (1995, pp. 236-7) describe its meaning within Microsoft:

> A product architecture is the skeleton that is internal to a product; it defines the major structural components and how they fit together. A product architecture and the components that fit into it provide the backbone for implementing the product features (that is, doing the detailed design and coding). … The product architecture is also the skeleton that determines the long-run structural integrity of a product. Any evolutionary change in a product’s functionality should not cause the underlying product architecture to unravel.

One can thus think of a software product’s architect or architects as making strategic decisions about basic system structure and interface specifications; it is left to programmers work within these strictures. The decision to use the same code in Windows 98 to display both web pages and information about the computer’s hard disk was architectural, for instance. As the passage above stresses, a good architecture permits considerable change in a product’s functionality without compromising its structural integrity. On the other hand, if the desired change in functionality is fundamental enough, particularly if the desire for change is driven by a change in the (hardware) environment, the product architecture must be modified or abandoned.

The term also is applied to building construction, of course, but in this context it has several meanings. The ones closest to what is intended here, from Websters, are “a unifying or coherent form or structure” and “a method or style of building.” The conventions of gothic architecture, for instance, both limited the decisions to be made by church designers and steered that design process in fruitful directions. Those conventions remained in force for centuries, and they were flexible enough to permit the construction of a variety of distinct structures, but they were abandoned as building designers began to reject their substantive implications.

The creation of individual laws, treaties, protocols, or regulations is shaped by a *policy* architecture, a set of governmental structures and associated principles that constrain what can and must be decided. The policy architecture for the United States is set by the Constitution, as interpreted by the Supreme Court. Laws are drafted and debated with the understanding that, for instance, states cannot enter into international treaties, and *ex post facto* laws are forbidden. Such understandings are altered by constitutional amendments only on those infrequent occasions when it is widely accepted that they are pointing the process of policy development in undesirable directions. Note that this kind of architecture, like gothic architecture (but unlike that of Windows 98) is not necessarily associated with a single architect or even necessarily with a well-defined group of architects.

In many contexts, past policy debates, legislation, and regulatory decisions also provide important architectural elements. Debates about the personal income tax, for instance, have long taken as given the desirability of such a tax, as well as of some degree of progressivity, and the legitimacy in principle of the distinction between deductible and other expenses. While elements of this sort, like constitutional provisions, may be debated from time to time, mainly they are accepted

[1] For a general discussion of the long-run aspects of the climate issue and their short-run implications for policy, see Jacoby, Prinn, and Schmalensee (1998).

and thus serve to simplify decision-making. It is much easier to reach consensus about changing deductions for business lunches or top-bracket tax rates, for instance, than to produce and enact a completely new tax code each year.

A policy architecture doesn't have to be "best" in any sense—or even correct—in order to be useful. It may be often impossible even to rank alternatives, let alone to devise one that is optimal. For example, it is unclear whether it is somehow better to build tax policy around a personal income tax, as in the U.S., or around a value-added tax, as in the E.U. Furthermore, sound policy can be built on incorrect propositions, so long as they do not rule out desirable policy outcomes. For example, an element of the architecture guiding negotiations over the acid rain provision of the 1990 Clean Air Act Amendments was the implicit assumption that the environmental effects of a ton of sulfur dioxide were the same, no matter where in the continental U.S. it was emitted. This assumption is clearly false, but it helped simplify the negotiations, and it does not seem to have led the policy process seriously astray in substantive terms (Schmalensee *et al.*, 1998).

On the other hand, architectures can be plainly counter-productive. For instance, the Clean Air Act Amendments of 1970 required that national ambient air quality standards for seven criteria air pollutants be set at levels "requisite to protect human health" (U.S.C. 42 §7409(b)(1)). This policy architecture, which has directly shaped almost 30 years of standard-setting, rests on the assumption that there are threshold levels of concentration, below which each pollutant is safe and above which it is dangerous. In a world without such "bright line" thresholds, this architecture presumes information that doesn't exist, and in the process retards the search for understanding of the effects of alternative stringency levels. Getting the architecture wrong can have long-lived procedural and substantive costs.

With this definition in mind, we now turn to an assessment of the Framework Convention on Climate Change (United Nations, 1992), which is the basic document where an architecture for the climate issue is being laid out.

3. THE LEGACY OF THE RIO-BERLIN-KYOTO PROCESS

3.1 Key Elements of the Framework Convention on Climate Change

The Framework Convention on Climate Change (United Nations, 1992) is an agreement to which parties only adhere voluntarily. Each step in its development must be sought in freewheeling negotiations involving almost all world nations, where the views and actions of a dozen or more key states are crucial to any collective outcome. What will emerge over time can be no more than sets of actions that sovereign parties find in their national interest. Much effort has already gone into this process, as it has evolved from the pre-Rio negotiations, through the first Conference of Parties to the Convention (COP-1) in Berlin, and to COP-3 in Kyoto. As a result, subsequent stages will involve extension and/or modification of the structure created in the past few years. For our discussion we first highlight what we believe are five of its key features:

- Negotiation of budget periods, one at a time,
- The use of a recent baseline to judge new commitments,
- Provision for some form of emissions trading,
- Evaluation of the adequacy of commitments based on an atmospheric target, and
- A distribution of burdens heavily influenced, if only implicitly, by ability to pay.

Then in Section 3 we lay out architectural features that are yet missing from this structure.

Budget Periods, Negotiated on a Rolling Basis. A process is emerging whereby nations negotiate limitations on their emissions for a specified future period, with the procedure repeated as we move into the future. In contrast to other environmental agreements, such as the Montreal Protocol, it has not been possible to agree to a multi-decade path of commitments or the prohibition of particular activities. The first agreement in this form in the climate area, foggy though the negotiated text may have been, was the statement in the Convention document to the effect that,

> [Annex I parties] shall adopt policies and take corresponding measures . . . with the aim of returning [by the end of the present decade] individually or jointly to their 1990 levels [of] these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol (United Nations, 1992, Article 2, paragraph 2 [a and b]).

The article made no reference to emissions *after* the year 2000.

Many nations agreed to this target. All but a few will fail to meet it. However, even before national performance under the year 2000 commitment was known, COP-1 in Berlin instructed the negotiators to seek a set of "quantified emissions limitation and reduction objectives" for the years 2005, 2010 and 2020. In eight sessions of the Ad-Hoc Group on the Berlin Mandate (formed to carry out the decisions made in COP-1) and final long-night sessions at COP-3 in Kyoto, the system of emissions targets was refined to apply to a "commitment period" instead of a specific year, and a set of nation-by-nation reduction percentages was agreed for the first such period, 2008 to 2012.

If ratified and put into force, the Kyoto targets will have greater force, under international law and the domestic law of some countries, than the "aim" written into the original Convention. But even if some nations fail to agree to the Kyoto targets, or to live up to the commitments they do make, we think it likely that this sort of rolling negotiation will to be repeated. Indeed, the Kyoto Protocol anticipates a second and subsequent budget periods, and specifies that consideration of commitments for a second period shall start at least seven years before the end of the first period, i.e., by 2005. This approach is politically practical and, as we argue below, and it can be made consistent with a serious concern for the long-term dimensions of this issue.[2]

Emissions Reductions Based on a Recent Data Point. Beginning with the Convention's original aim of returning to the 1990 emissions by 2000, and continuing to the Kyoto Protocol, target reductions have been set with reference to emission levels in a near-past year. Most commitments have been described in terms of a 1990 benchmark, and procedures have been developed to provide consistency in these estimates (United Nations, 1996). In a key exception, to be discussed further below, nations "under the process of transition to a market economy" (i.e., states of Eastern Europe and the former Soviet Union) may choose a year other than 1990, which allows them to set their baselines at the higher emissions levels experienced before the economic decline of the late 1980s.[3] Note that the benchmark is the individual party's own historical emission level, not some absolute standard such as tons of carbon per capita or per dollar of GDP, or the performance of some other nation. It does not seem plausible to us that any such external standard will be agreed to by the nations involved. The pattern of negotiating commitment levels in relation to a recent historical benchmark is consistent with the privileged role assigned to the status quo in most policy debates, and, if only for that reason, this pattern is also likely to continue.

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[2] One of us has argued elsewhere (Schmalensee, 1998) that it would be better to assess each nation's compliance with its obligations *ex ante*, by evaluating the likely emissions reductions from policies it has adopted, rather than *ex post*, by measuring actual emissions. The precedents established by international agreements do not seem to rule out a shift in this direction, but neither do they suggest that such a shift is likely. For purposes of this analysis, we will concentrate on the current "targets and timetables" approach.

[3] The other exception to 1990 as the base year include the accounting of HFCs, PFCs and $SF_{6,}$ for which parties may chose either 1990 or 1995.

Emissions Trading. The Kyoto Protocol provides several mechanisms that allow a nation to seek credit for emissions reductions outside its borders. Joint Implementation applies to the nations of Annex I, and a Clean Development Mechanism has been introduced in the search for a way to foster transactions between Annex I and Non-Annex I parties. However, the most important potential feature, in terms of its future role in facilitating emissions reductions, is the provision for emissions trading. Much remains to be resolved regarding the definition of this component, and these details must be worked out in a situation where some nations continue to oppose such trading on principle. Nonetheless, it seems to us that, perhaps accompanied by some restrictions as to amount, international trading of emissions is emerging as a key architectural feature of the climate regime.

An Atmospheric Target as a Guide to Adequacy of Commitments. The ultimate objective of the Climate Convention, as stated in Article 2, is to achieve

> … stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner. (United Nations, 1992)

Considered as an element of a durable policy architecture, this objective gives one pause: it presumes the existence of a threshold level of greenhouse gas concentrations that at worst may not exist at all and at best may be impossible to infer from scientific findings for many decades. On the other hand, it is hard to escape the notion that if the climate change problem is serious, seeking to limit human intervention at some level is a logical part of the response.[4]

The international negotiation process seems to be building toward an attempt to agree to a specific number for this target, probably stated in CO_2 equivalents. The choice of level probably will be among the five (350, 450, 550, 650 and 750 ppmv) selected originally by IPCC Working Group I (IPCC, 1996) for its construction of stabilization scenarios.

In a system of rolling period-by-period negotiations, the concentration target is an input to debates whether nations are taking stringent enough actions to limit emissions. Its role can be seen in the carrying out at COP-1 of the provision of the Convention calling for review of the "adequacy of commitments" (United Nations, 1992, Article 4.2(d)). The idea of stabilization was implicit in these COP-1 discussions, and it influenced the conclusion that measures to date were not adequate, even though no numerical target had yet been selected. In future negotiations the goal of stabilization will likely play the same role, with its influence increased if and when an explicit greenhouse gas concentration target is adopted.

Because of its role in future negotiations, and because there is no scientific basis for a establishing a "danger" threshold, of this atmospheric target has become a key variable in a high-level debate about the risks, benefits and costs of emissions control. So far as we know, no nations have argued for a target of 350 ppmv. The global concentration of CO_2 alone (ignoring other greenhouse gases) is already at around 360 ppmv, and the emissions reductions required to stabilize concentrations at this level over the next century or two is perceived as too costly relative to the benefits involved. By the same token, we have heard little or no support for a 750 ppmv target. With no emissions controls at all, most long-range forecasts show CO_2 concentrations rising to well above 750 ppmv, implying significant costs to stabilize even at this high level. However, among those who

[4] Here we focus on concentration targets in the long term. The rate of change also may be important. Its inclusion is a possible extension of the approach explored below.

are willing to consider these targets at all, the implicit benefit-cost tradeoff seems to indicate a number less than 750 ppmv.

In the range of 450 to 650 ppmv, there is discussion. Groups with a high estimate of the risks of perturbing the atmosphere relative to the costs of foregoing carbon-producing activities (environmental NGOs among them) argue for 450 ppmv. Others, showing a stronger concern with the costs of restricting these activities and perhaps less worry about the environmental risks, say that even 550 ppmv is unreasonably stringent, but perhaps 650 ppmv is plausible. Within this implicit benefit-cost discussion, it now seems likely that the balance of forces will lead to the selection of 550 ppmv. This level has the attraction of being in the middle of what has become the standard range of numbers, making it appear a moderate compromise. Also, it is roughly the standard doubled-CO_2 case used in climate-modeling studies over the past two decades, giving it the advantage of familiarity. The E.U. has already proposed it.

Of course, such a target level would not necessarily remain constant in the long run, wherever it might be set initially. Technological developments or lower economic growth could reduce the expected cost of emissions control, and/or some combination of weather events and scientific results could heighten fears of climate damage, creating demands to tighten the target to a more "precautionary" level. And *vice versa*. Thus a policy architecture that uses such a target as a guide to "adequacy" of near-term control commitments must be able to adapt to changes in the target itself.

Differentiation of Burdens Based on Ability to Pay. Here we must look hard to see the statue within the stone, but we cannot imagine a workable policy architecture for this or almost any other large cost-sharing problem that does not assign a central role to considerations of ability to bear the burdens. Certainly from the early stages of the climate negotiations, nations have been classified, roughly, by income level when discussing who should make what sorts of commitments. For example, the Framework Convention divides parties into three categories, plus one aggregate:

- **Annex II**. This group includes the rich nations, and is roughly equivalent to the membership of the OECD in 1990.

- **Economies in Transition**. As noted earlier, this group encompasses the nations of Eastern Europe and most of the Former Soviet Union, which have much lower incomes than most OECD countries.

- **Annex I.** This is the aggregate, a combination of Annex II and the Economies in Transition.

- **Non-Annex I.** This is the developing world, some with per-capita incomes akin to the less successful of the Economies in Transition, but most being far poorer.

In both the original Convention text and the instructions to negotiators at COP-1 (the so-called Berlin Mandate), any obligation to limit emissions applies to Annex I parties only. Discussion of such commitments by the lower-income Non-Annex I group has been ruled off the formal agendas of the Conference of Parties and its subsidiary bodies.

Also, a division is made within Annex I itself: from the outset the Economies in Transition were to be given "a certain degree of flexibility" within the process (United Nations, 1992, Article 2, paragraph 6), presumably to account for their lower economic status within the Annex I group. The provision noted above, allowing a baseline other than 1990 is part of this flexibility. This distinction extends to that portion of the Convention dealing with aid to developing countries—assistance to help them comply with their obligations (mainly by supporting data development and analysis), aid to countries particularly vulnerable to climate change, and promotion of technology transfer.

Of course, criteria other than ability to pay necessarily enter the negotiations. Nations seek credit for any past controls leading to an already-low emissions rate, some claim to be particularly disadvantaged by the choice of a base year, and some call attention to particularly high emissions control costs. Emissions per capita and historical responsibility for existing atmospheric concentrations are proposed as indicators of special obligation. Geopolitical factors matter, which helps explain why the Economies in Transition were included in Annex I as a bloc, when some of them are poorer than nations of the Non-Annex I group. Nevertheless, considering all nations participating in the negotiations, it is hard to escape the notion that the most pervasive criterion thus far has been per capita income, treated as a measure of the economic ability to bear the burdens of emissions controls. Indeed we expect differentiation on this basis to become more explicit, if serious limits on global emissions are agreed, because such agreements require the participation of poor nations, thus widening the range of incomes of nations with control obligations.

A striking example of the apparent influence of income level can be seen in the results of the allocation among E.U. members of proposed Union level reductions. The E.U. went through this process twice: once before Kyoto, allocating an anticipated 10% Union-wide reduction below 1990 emission levels, and once after Kyoto to apportion the 8% reduction agreed to there. Figure 1 shows the results of these intra-E.U. negotiations. Ability to pay clearly matters; equally clearly, it is not all that matters. Still, on average the richer countries are expected to make larger percentage reductions in emissions, and the poorest nations are even given room to increase emissions as they attempt to catch up economically.[5]

3.2 NEEDS OF FUTURE NEGOTIATIONS

Although elements of a policy architecture for the climate issue have been worked out in the Rio-Berlin-Kyoto process, there are many contentious issues on which agreement has not been possible. As noted earlier, there is yet great controversy over proposed flexibility mechanisms, and crucial details remain to be worked out on credit to be given for carbon sinks. Also, the credibility of the entire policy regime requires further achievements in the area of monitoring and enforcement. We have argued the importance of these topics elsewhere (Jacoby, Prinn, Schmalensee, 1998; Schmalensee 1998), and they remain crucial elements of any useful architecture.

However, we concentrate here on the no less essential task of extending the emerging policy architecture described above to handle issues of burden-sharing over time in a useful way. We focus on two important problems that such an architecture must address: negotiating accession of developing nations, and replacement of current baselines in rolling negotiations that will likely be repeated over many decades.

Negotiating Accession by Non-Annex I Parties. The division of nations into two fixed camps on the emissions control question, Annex I *vs.* Non-Annex I, creates a negotiating deadlock that somehow must be resolved. It is not disputed that the stabilization goals discussed above cannot be met unless emissions controls by Annex I are accompanied by action on the part of major Non-Annex I parties (Jacoby et al., 1997; Jacoby, Schmalensee and Reiner 1997). Indeed, some players, importantly including the U.S. Senate (1997) oppose any action whatsoever without participation by major emitters, present *and* future.

On the other hand, major Non-Annex I nations, particularly the poorest among them, have clear incentives to oppose any formal discussion of control obligations on their part. For many, climate is

[5] A plot of all nations, taking account of the Kyoto commitments and the EU internal allocation shows a similar but much more complicated pattern. It is a topic which merits further empirical analysis.

not high on their social (or even environmental) priorities. Even those giving it substantial weight may draw a clear division among parties out of moral and equity arguments familiar in North-South debate, and they have good reason to doubt that developed countries would increase foreign aid enough to help much with the cost of obligations they are encouraged to assume. Moreover, they have good strategic reasons to postpone discussions of control obligations which include them as well as the rich nations. Climate change has already claimed a place on the wider foreign policy agenda of the United States (and presumably other major developed countries) and large LDCs like China and India. These developing countries may well believe that their future bargaining power is strengthened (perhaps leading to larger aid flows, or more favorable conditions of later entry into the control regime) if they face no agreed structure of universal obligation.

Smaller, more wealthy developing countries like Chile or Singapore have a related but different set of incentives. They also are recipients of foreign policy pressures from the United States and other Annex I countries, but being small they may be more susceptible. Also, some are close to membership in rich nation clubs like the OECD, or have already joined. Considerations of this sort surely go a long way to explain why nations like Romania and Estonia are in Annex I. As a result, some of these countries might be willing to accede voluntarily to Kyoto-style emissions targets, provided they are loose enough (providing sufficient "headroom" in climate jargon) not to threaten future economic growth. In Kyoto, however, a proposal to allow such voluntary accession was defeated on the opposition of China, India and others, for a complicated set of reasons very likely including the tactical ones suggested above. Clearly, resolution of this deadlock is a key step in the evolution of an architecture for the long run.

An Evolving Baseline. As described above, discussions to date of commitments to control national emissions have been based mainly on a 1990 emissions baseline. In just the seven years from 1990 to COP-3 in Kyoto, however, economic conditions had changed in unanticipated ways in many countries, complicating the negotiations. The continuing troubles of the former Communist states and the long and unanticipated U.S. expansion are obvious examples. By 2005, when discussions of the second commitment period are to begin, 1990 will be 15 years in the past. Some nations will be much richer than in 1990; some will not be. Some may have made progress with emissions controls, others will not. Discussion of relative burdens in terms of percentage reductions below 1990 will either be hopelessly artificial or will require a complex set of country-by-country corrections, in effect updating the baseline. Thus rolling negotiations will require a rolling baseline, with emissions reductions calculated from a base measured as close as possible to the date of new decision. The Convention process, which has been taxed by the demands of establishing emissions baselines for 1990, will soon need to focus on establishment of a procedure and timeline for continual updating of these national inventories.

This observation about economic surprises also has implications for the policy analysis task. It is conventional in economic modeling studies to assume a long-term forecast of no-policy GDP, and to compare burdens in terms of departures from this counterfactual trajectory. We do this below. The procedure is reasonable in *ex ante* evaluation of a policy. But burden estimates calculated from some long-ago forecast will have little relevance for negotiations over time. At the point of negotiation of the distribution of future burdens, what will matter most is the costs of the next round and the abilities of different nations to bear them.

Finally, there is the question of what happens when a country fails to meet (or more than meets) its commitments for some particular budget period. Only time and experience will tell, but it seems likely that each new budget period will be free from the hangover of earlier periods. Countries which reduce emissions more than promised may gain some bargaining advantage in the next round, and those over their quota may lose it, but so many exogenous factors (such as recessions and booms) will have contributed to these results that it will be hard to require formal adjustments to future commitments based on previous emissions performance.[6] It is worth noting, for example, that performance on the Rio commitment (returning to 1990 levels by 2000) seemed not to be a factor in setting Kyoto targets. Moreover, the COP quickly dropped the U.S. pre-Kyoto proposal that nations be automatically penalized in the subsequent budget period for any emissions above their commitments.

4. Developing a Useful Architecture

Here we consider one possible way to move from the collection of features described above to a more complete and more useful climate architecture. We use simplified models for illustrative purposes. We consider first how it might be possible to evaluate the "adequacy" of proposed emission control commitments in light of an agreed-upon stabilization objective. Such an evaluation procedure would serve to impose a useful discipline on negotiations. We then introduce a class of rules for accession and burden-sharing that depend only on ability to pay. The characteristics of our simple architecture are explored numerically in Section 5.

4.1 Definition of a "Stabilizing" Path

Much of the analysis of stabilization targets has been carried out using two sets of atmospheric CO_2 concentration profiles. The first of these was created by Working Group I (WG-I) of the IPCC for its Second Assessment Report (IPCC, 1996). The IPCC specified concentration trajectories which stabilize the atmosphere by some time in the mid-22nd century, and used a model of the carbon cycle (in an inverse calculation) to generating a corresponding emission paths. To stimulate consideration of important economic effects of the choice of path, Wigley, Richels & Edmonds (1996) proposed an alternative set of paths (usually denoted WRE) that exhibited higher concentration levels in earlier periods but, assuming the same model of the carbon cycle, stabilized CO_2 concentrations at the same ultimate levels over the same time horizon. The WRE paths shifted the burden to the future, assuming more drastic cuts in later periods.

The WG-I and WRE emissions paths underlie a growing body of research into the economic and environmental implications of the choice of an atmospheric concentration target. In model studies by Jacoby, Schmalensee & Reiner (1997), Yang & Jacoby (1997), and Manne & Richels (1997), and others, these trajectories are imposed as constraints on global emissions, for study of the welfare effects of alternative procedures for allocating emission reduction burdens among world regions. While these studies are instructive, their emphasis on *global* cost-effectiveness tends to underplay important distributional realities of climate change negotiations, and how they might be worked out over time. As at Kyoto, negotiations will be continue to be about emission levels in the near future, not about emission trajectories over several decades.

We take a different approach here, therefore, and specify a family of rules for allocating emission reduction burdens based on ability to pay. We consider a simple structure in which a member of this family is chosen in each round of negotiations. In order to judge the adequacy of a proposed choice, we ask whether or not that rule, if maintained over time, would meet whatever atmospheric stabilization target has been selected in current or prior negotiations, given an agreed-upon reference set of assumptions about future economic growth and technical progress. There would, of course, be no presumption that future negotiations would in fact simply adopt the same rule chosen in the past. A different rule leading to the same atmospheric concentration goal may have become more attractive, or a different concentration goal may seem more sensible.

[6] We are assuming here that the international regime continues to be of the "targets and timetables" variety. See note 2, above.

It is not totally straightforward to test whether a particular rule does in fact stabilize atmospheric concentrations of greenhouse gases. For simplicity we focus on CO_2. Let us define an emission path as a series of *t* positive carbon emission allocations *C*(*r*, *t*) among regions *r* over a sufficiently long time horizon $[t_0, T]$:

$$C(r,t) > 0 \quad \forall r, t \in [t_0, T].$$

When these emissions propagate through the carbon cycle they result in a path of CO_2 concentration levels,

$$CO_2(t) > 0 \ \forall t \in [t_0, T].$$

In the abstract, one might want to define stabilization of atmospheric CO_2 concentration at target level *C** in some future target date $t_s \leq T$ as follows:

$$CO_2(t_s) = C^*$$

and

$$\left.\frac{\mathrm{d}}{\mathrm{d}t} CO_2(t)\right|_{t=t_s} \leq 0$$

In practice, however, it is impossible to hit targets of this sort exactly. We thus replace these two conditions by the following:

$$CO_2(t_s) = C^* + \varepsilon_l$$

and

$$\left.\frac{\mathrm{d}}{\mathrm{d}t} CO_2(t)\right|_{t=t_s} \leq \varepsilon_r$$

Determining whether the emissions path corresponding to a particular allocation rule results in a stabilizing concentration trajectory is thus analogous to a terminal condition problem. An allocation scheme will be consistent with stabilization at *C** over the horizon if at t_s the atmospheric CO_2 concentration exceeds the target level by not more than a tolerance ε_l, and exhibits a rate of increase of no more than ε_r ppmv per annum. To identify feasible emissions paths one must therefore specify ε_l and ε_r for desired values *C** and t_s.

In calculations below, *C** = 550 ppmv and t_s = 2150 (following the WG-I and WRE procedures for 550 ppmv), and an emissions path is said to stabilize concentrations at a particular target level if:

- The simulated concentration exceeds the target in 2150 by less than 10 ppmv, or has peaked at a level less than 10 ppmv above the target and has begun to decline $(0 < \varepsilon_l < 10)$, and
- In 2150 the rate of change in concentration is less than 0.5 ppmv per year $(\varepsilon_r < 0.5)$.

The tolerances that define this stabilization "window" can be made more or less strict depending on the needs of the analysis. For our purposes we need only to be able to define alternative paths that are roughly comparable in their climatic effects, so we can study the behavior of stylized burden-sharing schemes. Given the huge uncertainties in emissions forecasts over such a long horizon and in the carbon cycle, efforts at great accuracy are not only misplaced but potentially misleading.

4.2 An Illustrative Model of Accession and Burden Sharing

Our approach to accession and burden-sharing is to focus negotiations on the development of rules that relate short-term emissions reductions obligations, if any, to nations' characteristics in ways that are perceived as fair. Countries cannot be forced to accept and discharge emissions control obligations. The only alternative, even if the perceived environmental threat is severe, is voluntary participation. Taking some encouragement from the work of Grossman & Krueger (1995) who find evidence that nations value environment more as they become richer (the so-called environmental Kuznets curve), we make the key assumption that countries are willing to accede to an international emission reduction treaty and to accept commitments to emissions control based primarily on their ability to pay. Widespread reliance on progressive tax regimes reinforces the plausibility of this basic approach.

More specifically, we suppose for illustrative purposes that each country (or in our model analysis, region) becomes willing cut back its emissions once a threshold level of per capita welfare (a welfare "trigger") stipulated for accession to the international regime is exceeded. Otherwise, it follows its unconstrained (no-policy) emission trajectory. The rate at which each region reduces emissions in each period is a function of the welfare threshold w^* and a per capita welfare data-point in the immediate past (w_{t-1}), as follows:

$$\eta_t = \left(\frac{\dot{C}}{C}\right)_t = \begin{cases} \gamma - \alpha\left(w_{t-1} - w^*\right)^\beta & w_{t-1}^{ref} \geq w^* \\ \eta_t^{ref} & \text{otherwise} \end{cases}$$

Figure 2 demonstrates how this formulation captures the stylized facts of accession. The coefficient α influences the overall rate of emission reduction but has its greatest effect on nations with incomes only slightly above w^*. The term β, on the other hand, strongly affects emission reduction rates when incomes are relatively far above the accession threshold. The term γ mitigates the effect of α and β; it determines the maximum rate at which regions should slow the rate of growth of their emissions prior to beginning absolute reductions. By varying w^*, we control the timing of the protocol's entry into force in the different regions. In order to ensure that the stabilization objective is met, of course, variations in w^* generally require offsetting variations in the other three parameters. Overall, then, the stringency, distribution, and timing of emissions reduction burdens can be determined by the choice of values for parameters α, β, γ, and w^*.

The functional form for the rate η_t is intentionally made as simple and transparent as possible, to focus attention on the larger issues of accession and subsequent obligation. We would not expect such a simple family of functions to govern real negotiations. We are in effect proposing an income tax system here, and we are analyzing it by examining functions relating tax obligations to income—even though real income tax systems base tax obligations on a host of additional factors as well. We focus on this four-parameter version here for reasons of tractability, and we explore how it might serve to guide negotiators as they debate the many details that will inevitably engage their attention.

5. How Such a Structure Would Work

5.1 Calculation Procedure

To explore the implications of this structure for discussing burden allocation guidelines, we simulate a set of cases using the MIT Emissions Prediction and Policy Analysis (EPPA) model. EPPA is a recursive-dynamic CGE model based on OECD General Equilibrium Environment (GREEN) model (Yang, *et al.*, 1996). The world is represented by 12 nations and groups, as shown in Table 1. Each contains a utility-maximizing individual producer-consumer, each has eight production sectors and four consumption sectors, and all are linked by bilateral trade in both energy and non-energy goods. The endowments of each representative agent are updated at each step, according to assumed exogenous trends in rates of population growth, labor productivity increase, and technological change. Within the EPPA structure, the preferred welfare index is one computed from national/regional consumption, and it is used to define *w**. In this discussion we speak interchangeably about this index and income, because of their tight correlation.

The effects of emissions on atmospheric concentrations is modeled by the carbon component of the MIT Integrated Global System Model (Prinn *et al.*, 1998). The atmospheric target is assumed to apply to CO_2 alone, thus avoiding the complexities of aggregation of the radiative effects of the trace gases. The essential issues of policy architecture are not disturbed by this common simplification. A logical extension of our approach would be to include other greenhouse gases, which are also forecast by the EPPA model.

In all previous applications, EPPA has been run to 2100, or for some shorter period. To make our stabilization calculations comparable to others in the literature, the time horizon of the EPPA model has been extended to 2150. There is an element of heroism (or folly) in pushing a model of this type (or indeed any economic model) so far into the future, and distant results should not be taken too seriously. What the model results do show is which of the burden-sharing schemes we formulate makes even approximate sense as a guide to rolling negotiations. As we have emphasized above, the idea is that parameter values would be agreed to only for the near term; their adequacy would be evaluated by considering whether maintaining them in place in the long run would result in stabilization.

5.2 PERFORMANCE WITH NO EMISSIONS TRADING

Experiment with this system reveal that as long as the welfare threshold, *w**, is not set too high, a number of parameter value combinations, if maintained over time, produce trajectories consistent with our definition of stability. Differences in the values of our four parameters, like differences in income tax rates, translate directly into the burdens imposed on nations at different income levels.

For the sake of brevity, we focus in what follows on the implications of two parameter value combinations, one (the High case) with a relatively high value of *w** ($4500 in 1985 U.S. dollars) and one (the Low case) with a relatively low value ($3,000) of this parameter. The values of the parameters are the following:

High Case: w^*=\$4500, β= 0.25, γ=0.015, α=0.03
Low Case: w^*=\$3000, β= 0.20, γ=0.025, α=0.03

Figure 3 shows the trajectories produced in a regime without inter-region emissions trading, assuming these parameter values are maintained over the entire period. The timing of accession under the various cases is shown in Table 2. In the Low case, Non-Annex I nations take on control commitments earlier, so that it is possible for these obligations to rise less rapidly with welfare and still achieve stability. In the High case, for instance, our model and reference case parameter values imply that China assumes obligations in 2030, while in the Low case it does not do so until 2050. In general, if stabilization is a requirement, a decision to raise the threshold for accession (*w**) requires some combination of reduced “headroom” for the poorest countries with control obligations (lower γ) and more rapid increase in obligations with income (higher α and/or β). These are the sorts of tradeoffs that are the stuff of politics, domestic or international; they can productively occupy negotiators for long periods.

Also shown in Figure 3 are the WG-I and WRE cases for 550 ppmv. We follow the same procedure as for our own cases, in that we run WG-I and WRE emissions trajectories through the MIT carbon cycle model. The calculated concentration levels shown in Figure 3 differ somewhat from those presented by the IPCC (1996) and Wigley, Richels and Edmonds (1996). This result illustrates the existence of uncertainty about the carbon cycle models—which is in fact much larger than implied by the differences between the WG-I and WRI concentration levels in Figure 3 and those presented by their authors.

The paths resulting from our High and Low cases are similar to the WG-I result. They differ substantially from the WRE path, however, which implies no controls in the early decades, and then strong reductions in the middle to latter part of the next century. In the Stanford Energy Modeling Forum and elsewhere, emissions control schemes have been studied which would favor the WRE Path (e.g., Manne and Richels, 1997) but none is the result of a simple guideline for rolling negotiations of the type explored here.

Some discussions of long-term burden-sharing schemes take the position that fairness requires moving toward equal per-capita emissions across nations, and it is worth checking the performance of this structure of commitment under that criterion. The per-capita emissions implied by our High policy are shown in Figure 4 for the United States (USA), Europe (EEC), Japan (JPN), China (CHN), and India (IND). The effect of the Kyoto commitments are clearly seen in the early years for members of Annex I. By the latter part of the next century, emissions per capita have roughly converged.

Figure 5 shows the discounted welfare costs relative to our reference, no-policy economic scenario for each of the EPPA regions (see Table 1) for our High and Low cases. For the parameter values chosen, a move from the High to the Low case (with Non-Annex I countries entering earlier and a lower long-term reduction rate, β) the wealthier nations (USA, JPN, EEC, OOE) all benefit. For the others the result is mixed, and this result is due to the effects of leakage. All the poorer countries are helped by the $3000 as compared to the $4500 entry threshold. But under the $4500 trigger many were benefiting from carbon leakage (i.e., a shift in comparative advantage and carbon emissions because of the greater stringency imposed on richer countries). With the shift to $3000 trigger (putting less pressure on the USA, JPN, EEC and OOE), this economic benefit is lost. As a result, Eastern Europe (EET), energy exporters (EEX) and China (CHN) benefit overall from a shift to the Low case, but the others on balance do not. It is a complex phenomenon, worthy of further investigation with the EPPA model and perhaps with others. It is important to note, however, that Figure 5 reflects the costs of trajectories along which the values of all four parameters are constant from the present through 2150. While this is a useful summarization device, we cannot imagine a century and a half of negotiations actually leaving burden-sharing arrangements unchanged.

5.3 The Effects of Emissions Trading

Inclusion in the architecture of emissions trading would have a substantial effect on burdens, even under the same structure of allocation. Only full global trading, without restriction, has been analyzed for this illustration, so it gives an upper bound on the difference from an architecture without trading. We focus on the High case, and the calculation is made by simply applying the High case parameter values to a calculation where trading is allowed. Figure 6 shows that the High case parameter values, the addition of trading leads to a somewhat lower trajectory of emissions, although the 550 ppmv stabilization criterion is still met. (This also holds in the Low case.) Trading tends to raise incomes, activity levels, and thus emissions. On the other hand the higher incomes also cause some regions to enter the control system sooner, as shown in Table 2. For instance, more rapid income growth in China leads to its surpassing the accession threshold in 2045 instead of 2050.

Figure 7 shows what happens to per-capita emissions in the U.S. and China as a consequence of trading in the High case. As shown in Figure 4 above, China's per-capita emissions entitlement surpasses that of the U.S. in about 2070. When those entitlements are made tradable, however, per-capita emissions in the U.S. are far above the U.S. entitlement, while China finds it beneficial to control emissions more than its entitlement implies. (The picture for the low case is similar, though the no-trading paths have not crossed by 2150.) In this scenario, per-capita emissions in the U.S. continue to rise until around the middle of the next century, after which they decline more rapidly than those in China.

Figure 8 shows the effect of unrestricted full global trading on the costs of the High case. Consistent with earlier work on this aspect of a control regime, the addition of trading lowers costs (or increases benefits) across all regions. This result holds as well for the Low case, not shown here. Clearly, this is a crucial component of climate architecture, as suggested above.

6. CONCLUSIONS

We could easily devote more attention to the properties of the burden-sharing rule that we have added to the climate policy architecture. We do not, however, because we intend that rule only a simple example of the sort of rule that might emerge from rolling emissions-reduction negotiations, each using a different recent baseline. Such negotiations no doubt would produce more complex burden-sharing rules, just as the real income tax code is much more complex than a table of tax rates. The more complex the allocation produced by a particular negotiation, the harder it would be to verify that the underlying structure, if maintained over time, would lead to stabilization under reasonable assumptions. But we feel that some such test will prove necessary if the notion of a long-term stabilization target is to be made meaningful in a world in which it is impossible to commit to a long-term emissions trajectory.

We believe that in any fair regime, substantial differences in per-capita income will translate roughly into substantial differences in emissions control obligations, though of course other factors will matter in the negotiations. This argues that climate negotiators should begin now to consider explicitly how differences in real GDP per capita (for which internationally accepted data generally exist) should affect accession and burden-sharing.

At the most fundamental level, though, the argument of this paper is that climate negotiators are, like it or not, both arguing about short-term national commitments and building a policy architecture that will focus and shape future negotiations. We have indicated what elements the negotiations to date have contributed to a useful policy architecture, and we have explored one approach to completing such an architecture. But we do not intend to argue that our approach is the best; it is only the best we could think of. We would be surprised if hard work by smart people did not produce a better path to a useful policy architecture. This paper will have fully achieved its objective if it serves to stimulate such work.

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Table 1. EPPA Regions

Annex I	
Annex II	
USA	United States
JPN	Japan
EEC	E.U.: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK
OOE	Other OECD nations: Australia, Canada, New Zealand, the European Free-Trade Area (excluding Switzerland and Iceland), and Turkey
Economies in Transition	
FSU	Former Soviet Union
EET	Eastern European economies in transition: Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and Yugoslavia
Non-Annex I	
EEX	Energy-exporting developing countries: OPEC states as well as other nations exporting oil, gas, and coal
CHN	China
IND	India
BRA	Brazil
DAE	Dynamic Asian Economies: Hong Kong, Philippines, Singapore, South Korea, Taiwan, and Thailand
ROW	Rest of World

Table 2. Timing of Accession as a Function of Welfare Trigger, *w**

Regions	No Permit Trade		With Permit Trade	
	High *w**	Low *w**	High *w**	Low *w**
EEX	2020	2015	2020	2015
CHN	2050	2030	2045	2030
IND	2090	2065	2085	2060
DAE	2015	2015	2015	2015
BRA	2035	2020	2035	2020
ROW	n/a	2130	n/a	2115

Figure 1.
Implicit Differentiation: EU Burden Sharing *vs* Ability to Pay
(2008-2012 Commitment Period)

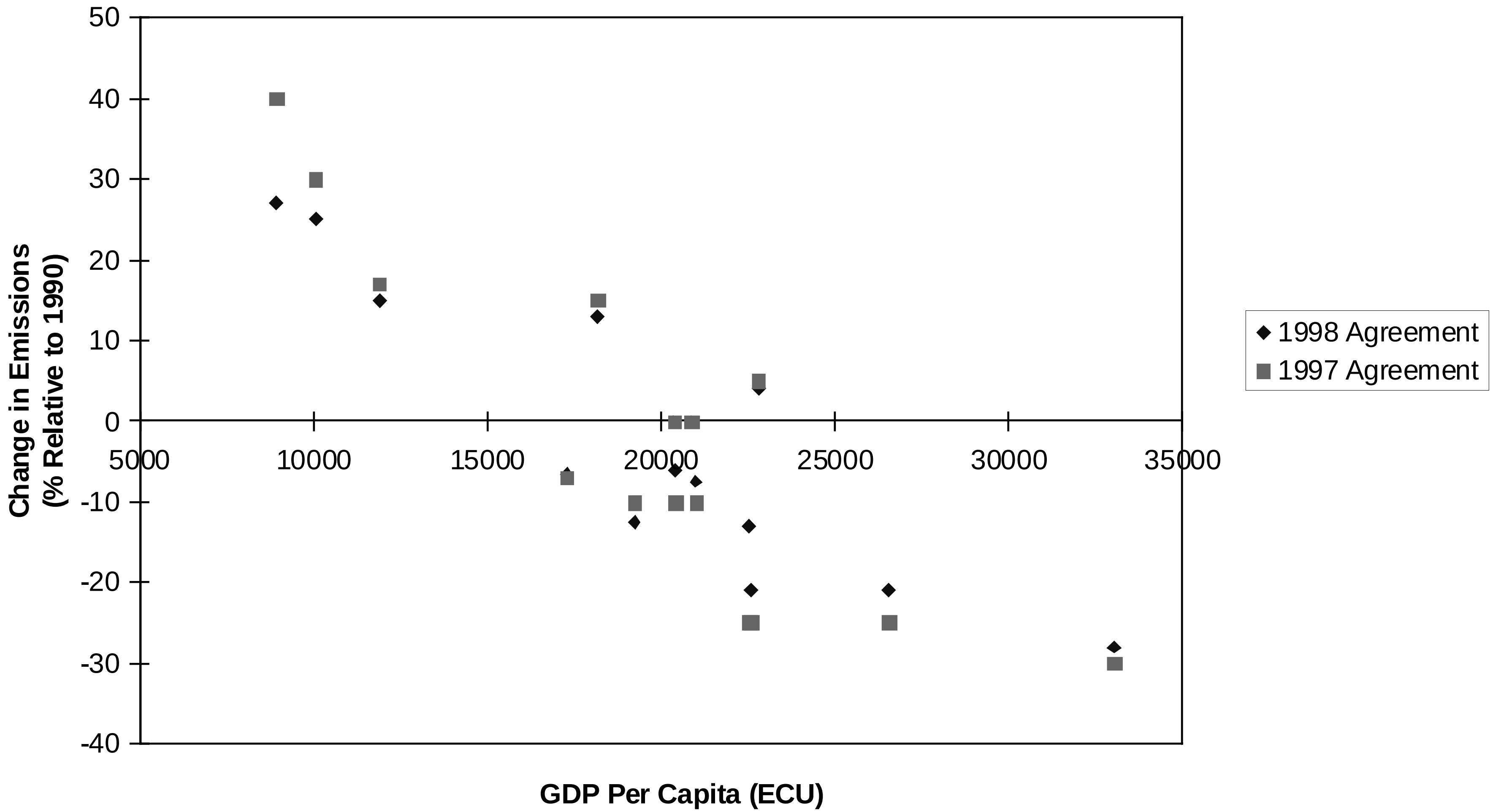

Figure 2. A Sample Burden-Sharing Scheme

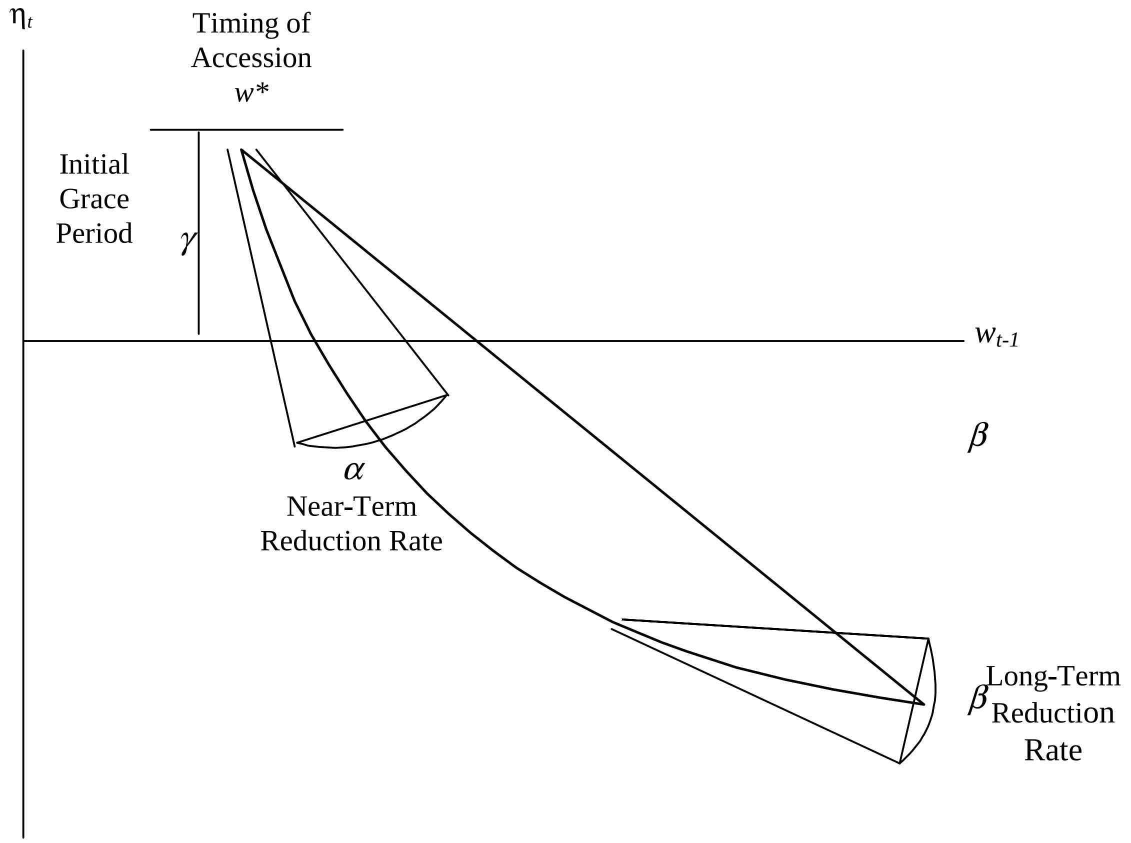

Figure 3.
Stabilization of Atmospheric CO_2 Concentration at 550 ppmv:
Low and High Welfare Thresholds (No Trading)

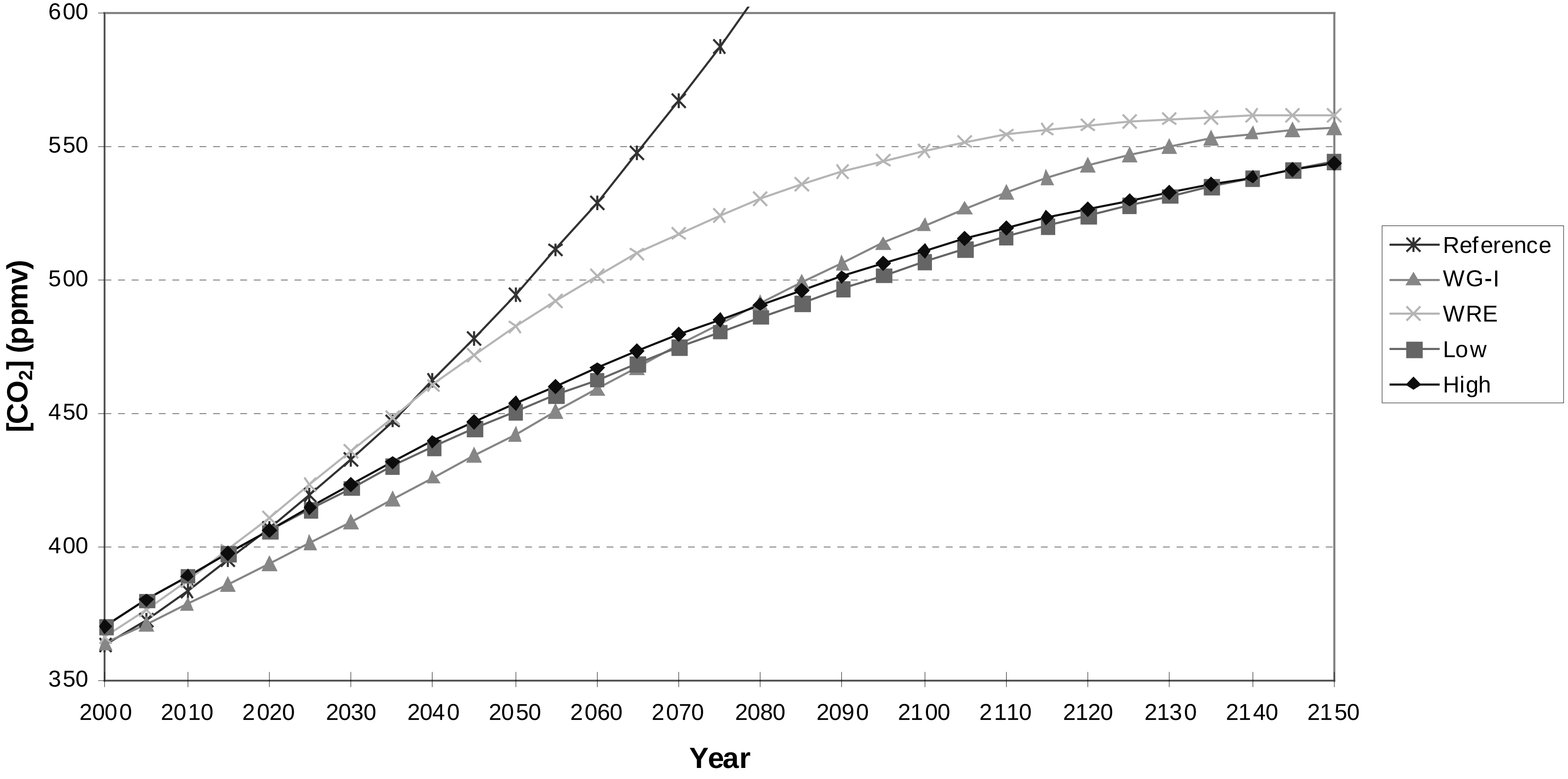

Figure 4.
Convergence of Regional Per Capita CO_2 Emissions
(*w = $4500, No Trading)**

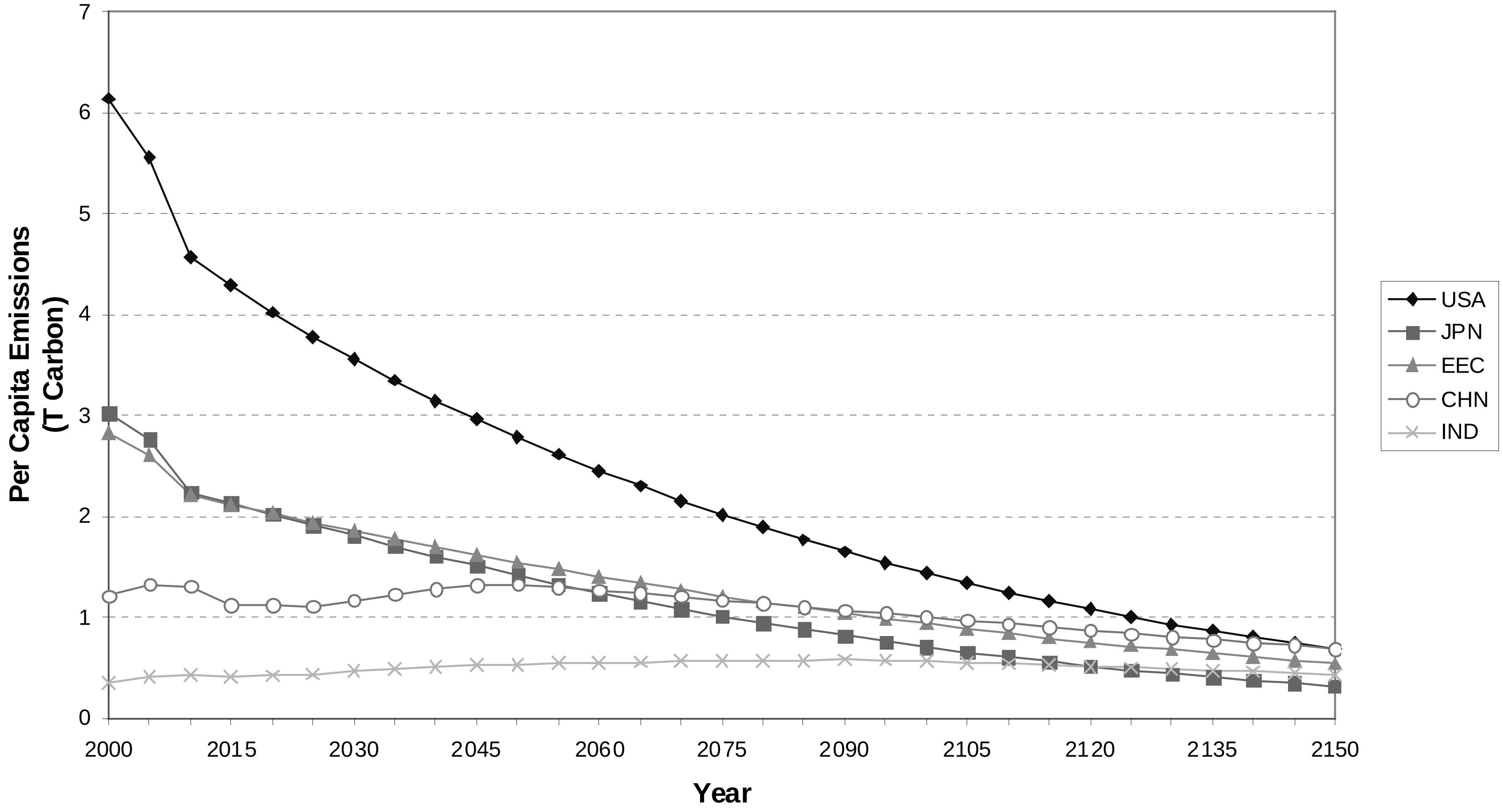

Figure 5.
Effects of Welfare Threshold on Distribution of Policy Costs
(5% Discount Rate, No Trading)

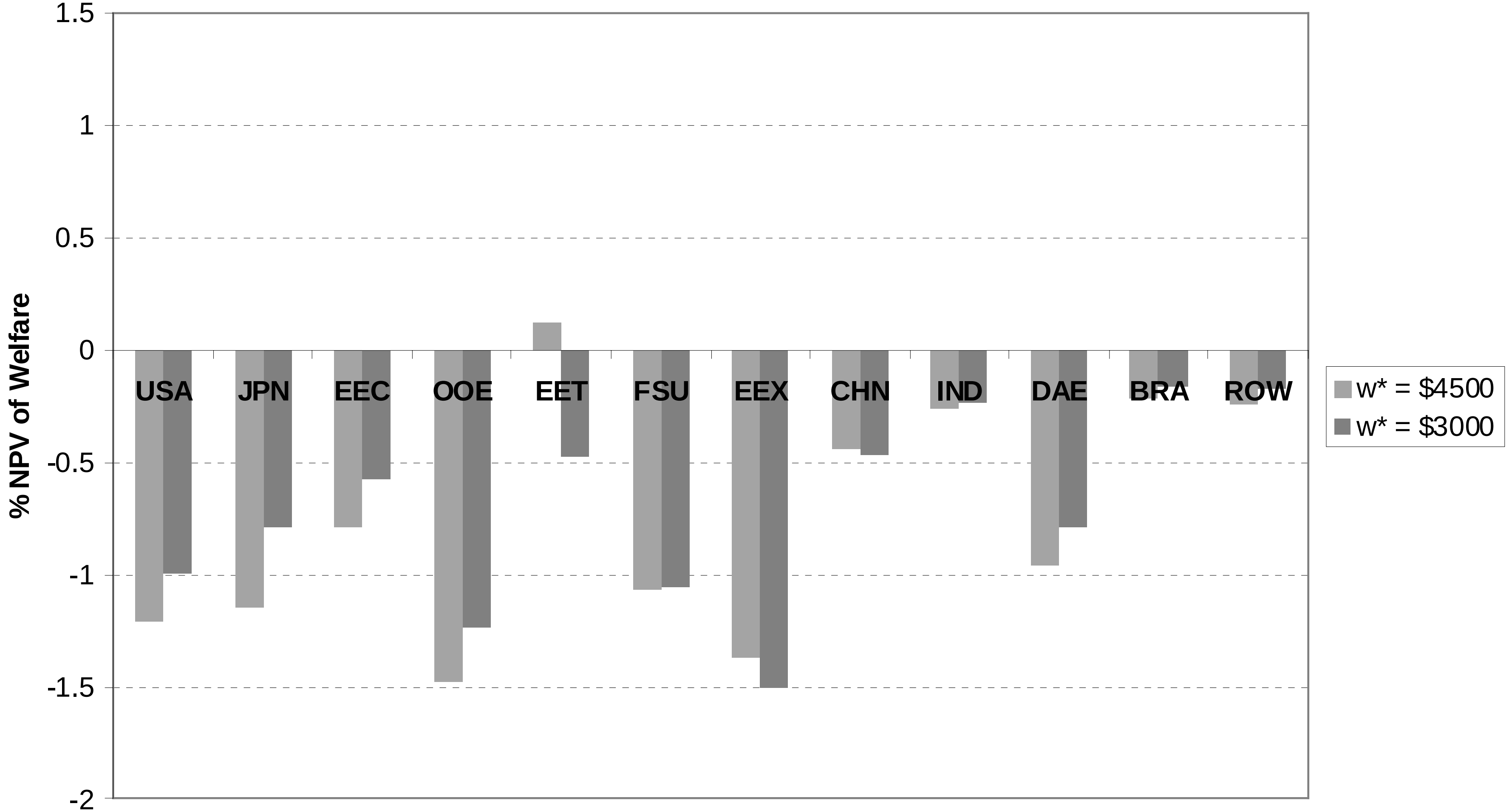

Figure 6.
Stabilization of Atmospheric CO_2 Concentration at 550 ppmv
Effects of Trading (*w = $4500)**

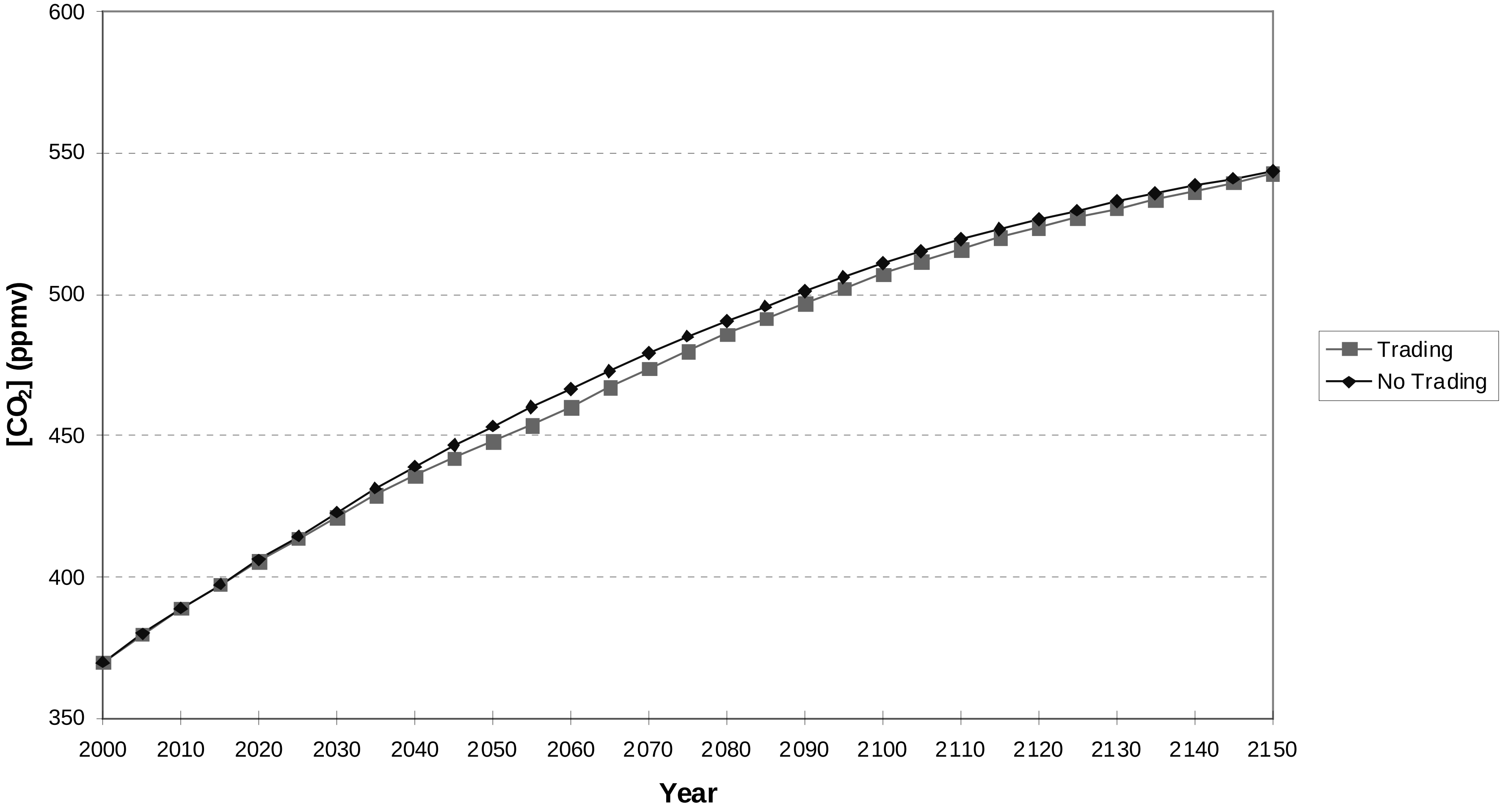

Figure 7.
Representative Per Capita Emissions
(*w = $4500)**

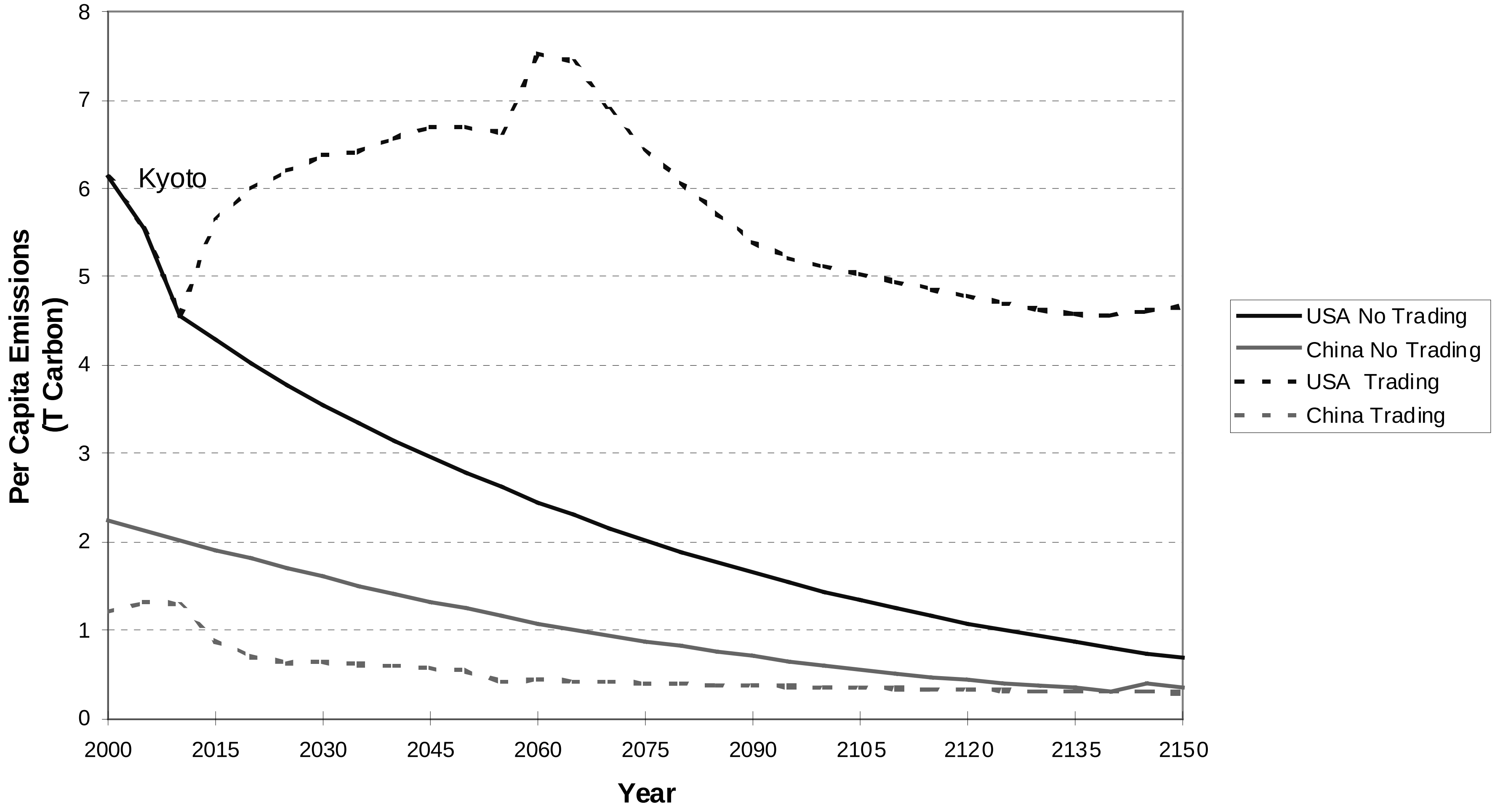

Figure 8.
Effects of Full Global Trading on Distribution of Policy Costs
(5% Discount Rate, *w = $4500)**