Journal of Applied Economics, Vol. I, No. 2 (Nov. 1998), 329-362

A DYNAMIC ANALYSIS OF FAIRNESS IN GLOBAL WARMING POLICY: KYOTO, BUENOS AIRES, AND BEYOND

ADAM ROSE*
The Pennsylvania State University

and

BRANDT STEVENS*
California Energy Commission

I. Introduction

In December 1997, 34 industrialized countries signed the Kyoto Protocol committing to targets and timetables to reduce 6 greenhouse gases (GHGs). Why were the only signatories industrialized countries? Two reasons are usually put forth. The first is pragmatism, in that only this group, as opposed to developing countries, can afford the costs of mitigating GHGs. Still, this explanation is imperfect since 12 of the signatories are transitional economies of Eastern Europe and the former Soviet Union. The second reason is fairness, in that industrialized countries are responsible for the vast majority of the

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* Adam Rose is Professor and Head of the Department of Energy, Environmental, and Mineral Economics, The Pennsylvania State University, University Park, PA. Brandt Stevens is an Economist with the Demand Analysis Office of the California Energy Commission, Sacramento, CA. The authors are grateful to Shu-Yi Liao for his assistance in enhancing the model and in running the computer simulations. They alone, however, are solely responsible for its contents. Moreover, the views expressed in this paper are solely those of the authors and do not necessarily represent the positions of the institutions with which they are affiliated.

GHGs already built-up in the atmosphere and are responsible for over 60% of the current emissions. The fairness explanation is further supported by the fact that "differentiation" was invoked in Kyoto, i.e., not all signatories agreed to equal cutbacks, several citing special economic circumstances.

In the future, both pragmatism and fairness will be relevant to the question of when and how developing countries will sign a global GHG agreement. Another major influence will be the pursuit of economic efficiency or, at least, cost-effectiveness, i.e., making sure that the targets are met at the lowest global cost. This can be fine-tuned in future agreements by the use of incentive-based instruments and the timing of commitments. Efficiency may also be affected by relative burden-sharing, since this will influence the number of countries that make mitigation commitments in the future.

The purpose of this paper is to analyze fairness, or equity, aspects of the current Kyoto Protocol and its extension to a truly global agreement that includes developing countries. This is done in the context of a policy approach gaining increasing favor—tradeable emission permits. A dynamic model of intercountry CO_2 permit trading is used to address the following questions:

1. To what extent does permit trading lower global CO_2 mitigation costs?
2. How are intercountry welfare impacts influenced by alternative permit distributions according to various equity criteria?
3. How might developing countries be brought into the agreement without requiring CO_2 reductions, yet promoting global efficiency gains by utilizing their relatively lower cost mitigation capabilities?
4. To what extent does allowing for permit trading over time further lower global mitigation costs?
5. How are intercountry welfare impacts distinguished by not just static definitions of equity but also dynamic versions, such as sustainability criteria?

We acknowledge some of the limitations of this paper at the outset. Only one of the Kyoto GHGs is examined. Also, policy-making over a 25-year time horizon extending to the year 2035 is fraught with uncertainty, which we do not address. Finally, our model is dynamic in the sense that it allows for intertemporal permit trading and changing benefits, but omits other dynamic considerations such as technological change.

II. Equity and Global Warming Policy

A. Basic Definitions

In this paper we distinguish between static and dynamic definitions of *fairness*, or *equity*. The concept is usually applied across entities (hence another synonym—*distributive justice*) in relation to important features of the policy in question. In the context of global warming policy the relevant entities are countries. For marketable permits the relevant features are the initial allocation of permits, post-trading welfare outcome, or the process by which the policy decisions are made. Fairness in one area of the policy, however, may have quite different implications in another, e.g., a principle that gives all countries an equal proportion of permits in relation to their initial emissions will not result in equal percentage emission reductions or equal percentage welfare changes following trading.

Static equity refers to a given point in time, and in our context will be referred to as *intercountry equity*. Dynamic equity refers to the situation over time, and is often referred to as *intergenerational equity*. Below we make a case for how these two concepts are separable from each other and from efficiency considerations as well when the marketable permits approach is used.

No universal agreement exists on the best definition of equity or even on the base or objectives to which it should be applied. Thus we explore the implications of several alternatives that have been put forth in the literature. Table 1 presents five static equity criteria, a general definition of each, a definition in the context of tradeable permits, and how each is made operational in terms of permit distribution.[1]

Note that the first three criteria are all "allocation-based," and are adapted from established normative principles of philosophy, law, or economics. On the other hand, the "No Purchase" rule,[2] often referred to as the "No Harm" rule, has been put forth as an objective or "acceptable" criterion (see e.g., Barrett 1992; Edmonds et al., 1995), but it can be demonstrated that it implicitly or explicitly involves value judgements, as do all distribution principles. For example, Rose et al. (1998) have explained how it is roughly equivalent to a Rawlsian maximin criterion. As we will demonstrate below, this rule appears to have great promise in inducing developing countries to join in a GHG protocol.

A good example of a purely ad hoc rule is the set of emission caps in the Kyoto Accord. These arose from the special pleadings of individual countries to obtain *differentiation* in commitments (e.g., Australia—high dependence on coal exports, New Zealand—long standing economic recession, Norway—extensive hydroelectric energy base and limited options for further lowering emissions, some transitional economies—economic decline due to restructuring). Although differentiation was intended to have a neutral connotation, all of these reasons are appeals to fairness.

In recent years, *dynamic equity* has been dominated by the concept of *sustainable economic development*, which has efficiency connotations as well. Like its static counterpart, there is no universal consensus on the dynamic version, but one often used criterion is that each successive generation be no worse off than its predecessor. Of course, we limit this rule to just the policy itself and not the entire development requirements per country, i.e., net benefits of GHG mitigation per capita at time $t+1$ must be

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[1] For a discussion of how each distributional rule presented in Table 1, as well as several others, can be given mathematical specificity and be formally modeled, see Rose et al. (1998).

[2] The two rules are equivalent when only costs are taken into consideration. When benefits are included, the No Harm rule is the "outcome-based" version of the No Purchase rule.

Table 1. Alternative Fairness Criteria for Global Warming Policy

Criterion	Basic Definition	General Operational Rule	Operational Rule for CO_2 Permits
Sovereignty	All nations have an equal right to pollute and to be protected from pollution	Cut back emissions in a proportional manner across all nations	Distribute permits in proportion to emissions
Egalitarian	All people have an equal right to pollute or to be protected from pollution	Allow emissions in proportion to population	Distribute permits in proportion to population
Ability to Pay	Abatement costs should vary directly with national economic well-being	Equalize abatement costs across nations (gross cost of abatement as proportion of GDP equal for each nation) [a]	Distribute permits to equalize abatement costs (gross cost of abatement as proportion of GDP equal for each nation) [a]
No Harm (No Purchase)	Some nations should not incur costs (Poor nations should not have to buy permits)	Poor countries should not be required to abate emissions	Distribute permits to poor countries equal to their baseline emissions
Ad Hoc (Kyoto Protocol)	Abatement costs should be sensitive to unique circumstances (differentiation)	Give special consideration to economic health, fossil fuel dependence, prior abatement, etc.	Distribute permits according to special circumstances

[a] Gross cost refers to abatement cost only and does not include benefits or permit transactions.

greater than or equal to those at time *t*. Sustainability criteria generally have both an economic and environmental connotation—the latter would require that environmental quality be of no lesser quality for future generations in each country. This can be promoted by stabilization of atmospheric CO_2 concentrations, which the Kyoto agreement caps were intended to help achieve. Therefore, we do not model this second requirement separately (the reader is referred to Stevens and Rose, 1998, for such an analysis).

B. Advantages of Marketable Permits

The agreement reached at the Third Conference of the Parties to the Framework Convention on Climate Change (COP-3) in Kyoto commits most of the industrialized nations to emission caps for each of six major greenhouse gases by the year 2010, as shown in the right-hand columns of Table 2. In addition, the agreement allows individual nations to achieve even lower emissions and to bank their excess reductions for later use. Countries can also develop projects for joint implementation (JI) of GHG emissions (FCCC, 1997).

Tradeable greenhouse gas permits had been proposed prior to Kyoto (see, e.g., Barrett et al.1992; Tietenberg and Victor, 1994), though only a few limited features of this instrument will be included in the Protocol. Economists familiar with permit trading will recognize the banking provision of the agreement as a limited form of permit trading in which individual nations can "sell" permits to themselves to be used in the future. Joint Implementation could also be viewed as another limited form of permit trading, where all trades are along bilateral lines rather in a market with many buyers and sellers.

Potentially sizeable gains in both efficiency and equity could arise from establishing more open and complete permit markets as a feature of an ultimate GHG treaty. First steps toward an unrestricted market would include permit transfers between at least the Annex I countries, credits for sponsoring mitigation in developing countries, and then including developing countries

Table 2. Basic Data for Year 2010

Country (Area)	GDP[a]		Population[b]		CO2 Emissions[a]		Mitigation Percentages			
	Level (billion $)	Growth Rate	Level (million)	Growth Rate	Level (million t C)	Growth Rate	1990[c]	2010[c]	2020[c]	2035[c]
Africa	393.7	4.0	741.2	3.0	296.2	4.6	0.0	0.0	0.0	0.0
Aus/NZ	382.0	1.2	23.3	1.3	82.0	0.8	-7.0	1.2	8.8	19.0
Canada	642.4	1.2	28.7	0.8	117.3	0.5	6.0	10.6	14.9	21.1
China	653.5	6.0	1290.0	1.3	817.5	2.6	0.0	0.0	0.0	0.0
E-Europe	337.9	1.9	126.1	0.2	290.9	0.7	6.0	12.3	18.3	26.4
FSU	575.7	1.9	151.7	0.2	1084.5	0.7	0.0	6.8	13.0	21.7
India	414.6	5.0	1005.5	1.7	267.8	3.8	0.0	0.0	0.0	0.0
Japan	3315.7	1.2	127.3	0.3	310.9	0.8	6.0	13.2	19.8	28.9
L-America	1345.2	3.3	509.8	1.8	374.2	3.2	0.0	0.0	0.0	0.0
M-East	685.5	5.0	287.9	2.9	310.9	3.8	0.0	0.0	0.0	0.0
Asian Tigers	797.4	5.0	74.7	0.4	161.5	3.4	0.0	0.0	0.0	0.0
S-Asia	591.6	4.1	835.9	1.6	241.4	5.1	0.0	0.0	0.0	0.0
U.S.	6075.3	1.2	270.7	0.8	1354.9	0.5	7.0	11.5	15.8	21.9
W-Europe	7825.7	1.2	468.2	0.8	977.2	0.7	8.0	14.2	20.0	27.9
Total	24036.2	1.9	5941.0	1.6	6687.2	1.7	3.5[d]	6.9	9.2	10.9

[a] IPCC (1996); Nordhaus and Yang (1996).
[b] World Bank (1996).
[c] Base case where developing countries have not joined Kyoto Protocol.
[d] Reduction percentage for Annex I countries alone is 5.0%.

as signatories. Further steps would be to allow interregional trading and trading of permits across time (including borrowing as well as banking).

The case for international trading of GHG permits rests on a well-known theorem by Nobel laureate Ronald Coase (1960). In this context, suppose that a specific quantity of transferable greenhouse gas permits, determined according to a GHG Protocol, is distributed without charge to its signatories. The stock of permits effectively sets an overall cap on emissions. Next assume that countries are allowed to exchange permits in an open market. This effectively gives each country a stake in the environment, which is valued by the market. A country whose marginal abatement cost is higher than the market permit price will buy permits from those countries whose marginal abatement costs are below it. When trading concludes, each country will hold the economically efficient amount of permits (i.e., marginal abatement costs across nations will be equal), independent of the initial distribution permits to each country.[3]

From a global perspective, tradeable permits establish a valuable property right that provides an incentive to protect the environment and to use it and other resources efficiently. At the same time, the equity implications of the Coase Theorem are ambiguous. Overall global wealth is maximized and is identical regardless of how the permits are initially distributed, but equity is highly dependent on the permit distribution (as well as on mitigation costs and benefits). This separability of efficiency and equity is another major advantage of tradeable permits. In many other approaches to policy making, concerns exist that pursuit of equity will lead to disincentive effects, thereby undercutting efficiency. At the same time, separability has been used as an excuse to ignore equity, since it has no bearing on the pursuit of what economists consider the primary goal in most contexts.

[3] This conclusion assumes that the transaction costs of permit trades are negligible and that each country's income is largely unaffected by the distribution of permits. Both assumptions are reasonable in the context of transferable GHG permits (see Rose et al., 1998; Chao and Peck, 1998).

However, there are cases, such as international treaties, where global efficiency may not be a rallying point and where equity instead may be paramount (see, e.g., Rose, 1992; Manne and Richels, 1995). This may very well be the case for global climate change, where efficiency pursuits alone may lead to major disparities in costs and benefits between countries. Moreover, individual country welfare is not addressed directly by global efficiency, but is subservient to what is often considered an abstract goal. Countries are more likely to join in an accord that addresses their own welfare and its relation to that of other countries directly.

Therefore, we can stand the traditional rationale for ignoring equity on its head. If efficiency is not affected by how permits are distributed, then let us fine-tune the distribution in any way necessary to pursue equity objectives.

Interestingly, this pursuit will actually promote efficiency as well. We have taken for granted the issue of the comprehensiveness of the number of parties to an agreement. If more parties can be enticed into it by appealing to their equity concerns, environmental quality will be further enhanced. If these parties have relatively lower abatement costs than the original signatories, overall economic efficiency will be improved.

Note also that the Coase Theorem generalizes to the dynamic context. Permit trading over time promotes even higher levels of efficiency by capitalizing on abatement cost differentials in different periods.[4] In this case the permit price is determined not only by benefit and cost considerations in the pure efficiency case (or simply cost considerations in the cost-effectiveness case) but also by the fact that the permits represent a fixed stock. Thus, there is an intertemporal opportunity cost (user cost) that influences their value. As in the basic model of the extraction of a non-renewable resource following Hotelling (see, e.g., Fisher, 1981), the price of a permit will appreciate in conformance with the market rate of interest. Buying and selling of GHG emission permits over time will be consistent

[4] This stems from the fact that GHG abatement costs change over time; implicitly abatement cost differentials are required in the static context to stimulate trading as well.

with this outcome.[5] Moreover, the dynamically efficient (post-trading) outcome is unique and insensitive to the intercountry (static) or intergenerational (dynamic) concepts of equity that might serve as the basis for alternative permit distributions at a given point in time.

The overall stock of permits over time depends on the global abatement requirement, which is derived from emission targets. As long as costs do not exceed benefits of increased tightening of this requirement overall, a sustainability definition of intergenerational efficiency can be applied globally. Likewise, it is possible to apply this sustainability criterion to individual countries through initial permit allocations or additional transfers. Also, the intercountry equity rule agreed upon by the world body of nations may change over time. The separability of the Coase Theorem can further be exploited in the dynamic context to fine-tune each of these considerations individually.

III. Determinants of Permit Trading

The exchange of transferable greenhouse gas permits is a function of differences in marginal abatement costs, which can stem from several sources. The most obvious source of cost differentials is different marginal cost of abatement (MC_A) functions among countries. However, even if two countries had the same MC_A functions, a cost differential would arise if they had different emission reduction requirements (placing them at different points on the function). Thus trading would arise on this basis alone among Annex I countries because of differences in Kyoto emission cap commitments.

Of course, there are differences in abatement cost functions among Annex I nations, though these functions differ more significantly between the group

[5] Various complications may modify this dynamic equilibrium result somewhat, e.g., the possibility that low cost mitigation options will be used in early years, thereby leaving only high cost options and thereby imposing additional costs upon the future (see, e.g., Rose et al., 1999).

of developing nations and the industrialized group (see, e.g., IPCC, 1996; Halsnaes, 1996). Permit exchanges among Annex I countries would reduce the group's total GHG abatement costs incurred by the Kyoto targets. (The abatement costs of individual sellers would increase, but would be more than offset by permit revenues, and each country's net benefits would increase as well.) It therefore follows that, if developing nations have MC_A functions that are generally lower than those of Annex I nations, finding a mechanism for admitting them to the permits market (even by giving them permits equal in number to their emissions every year) could effectively decrease global abatement costs.

There are also likely to be differences in abatement costs over time. With the relatively long period over which mitigation would occur, technological change could reduce these costs, perhaps substantially. On the other hand, rising abatement percentages over time (i.e., abatement levels relative to uncontrolled greenhouse emissions) will increase MC_A temporally. In addition, the discount rate will affect the perception of future costs. In the absence of technological change and rising abatement percentages, any positive discount rate will reduce future MC_A.

These dynamic considerations suggest the possibility that shifting abatement from times when it is relatively expensive to times when it is relatively cheap could reduce the present discounted value of global abatement costs. Interperiod trading of greenhouse permits could have two forms of outcomes. The first would allow for early abatement above the required targets; the permits created by these excess emission reductions could be "banked" and used in some future period. This type of exchange could be restricted so that the country creating the banked permits could be the only nation to use them later, or they could potentially be sold for future use by other nations. From an economic perspective, banking only makes sense if discounted MC_A is lower in the present than in the future. The second option, permit "borrowing," would result from the converse, i.e., discounted MC_A being greater in the present than in the future, perhaps due to technological change. Under this outcome, it is cheaper to defer abatement to the future, which can occur when permits are transferred to the present.[6]

Another dynamic consideration is the timing of commitments themselves. Individual country welfare will, ceteris paribus, be higher, the longer emission targets are deferred. This ties timing to fairness as well. However, total global welfare will not be affected by timing of commitments, as long as all countries are involved in permit trading during each year of the planning horizon (a painless process under a No Harm/No Purchase rule for developing countries), and as long as the cumulative stock of permits is fixed (again this follows from the Coase Theorem).

An interesting question arises as to the relative prominence of each of these motivations for trading. This has important policy implications. Climate change negotiations are a source of tension between countries, and it would help to have some advance knowledge of which factors are most effective at reducing costs, so that these options can be the major focus of attention.

In addition, improvements in policy instrument design for the sake of improving efficiency are likely to have differing implications for equity. For example, permit banking opportunities will favor some countries, while borrowing will favor others. The timing of abatement commitments for developing countries will influence inter-country equity as well. Often these implications will accentuate the tensions, though potential problems may be offset by additional transfers or a manipulation of permit assignments.

[6] Interperiod trading, whether it involves banking or borrowing, adds one complication not present in the interregional trading case. Interperiod trading changes the time path of greenhouse emissions, and hence changes when a warming will occur. Again, for any positive discount rate, this would affect the sum of the present discounted value of global benefits over time, hence net benefits will change if interperiod trading is permissible. Our analysis suggest, however, the amount of interperiod trading is likely to be relatively small in comparison to total global emissions.

IV. Empirical Analysis

A. Alternative Simulations

In order to evaluate the relative prominence of the various determinants of permit trading on efficiency and equity, we performed a number of simulations. They begin with the most basic institutional arrangement—CO_2 emission quotas for Annex I countries as set forth in the Kyoto Protocol—and progress to the ultimate form—a globally comprehensive and fully dynamic CO_2 emissions trading system. Essentially, each simulation incorporates an additional feature in a step-wise manner as follows:

1. No-trading (Kyoto-based emission quotas for Annex I countries)
2. Trading by Annex I countries only (Kyoto-based tradeable quotas)
   a. trading among countries or groups (interregional trading)
   b. banking
   c. banking and borrowing (complete interperiod trading)
   d. interregional and interperiod trading
   e. interregional and interperiod trading and intergenerational equity
3. Trading among Annex I countries and developing countries (Kyoto-based tradeable quotas for Annex I; equity-based quotas for non-Annex I)
   a. interregional trading (No Harm)
   b. banking
   c. banking and borrowing
   d. interregional (No Harm) and interperiod trading
   e. timing of developing country commitments (Target Dates and Sovereignty,/Egalitarian)
   f. interregional and interperiod trading and intergenerational equity

The timing simulation merits further explanation. Here we examine welfare impacts of alternative commitment dates for groups of developing countries. Note first that in order to keep the number of simulations manageable, we have modeled only a single set of developing country emission reduction levels. In essence, we assume that the emission quota for each developing country for the remainder of the time horizon will be equivalent to that of its gross CO_2 emissions at the start date of its commitment. For example, if Argentina and other Latin American countries were to become signatories to a GHG Protocol in the Year 2010, they would have no mitigation requirement the first year, but would have to abate CO_2 thereafter, invoking the reasonable assumption of baseline emission growth.[7] With respect to timing, we divided developing countries into the following two groups based on their per capita income (PCI):

Group A: PCI > $1,000	Group B: PCI < $1,000
Middle East	China
Asian Tigers[8]	South Asia
Latin America	India
	Africa

We ran two simulations: 1) All developing countries commit to quotas based on Year 2020 emissions, and 2) Group A developing country quotas and the start of their commitments is the Year 2010, and Group B developing country quotas and the start of their commitments is the Year 2020. While all of the above noted simulations have been run, only selected results are presented and discussed in this paper (the reader is referred to Stevens and

[7] There is an obvious problem associated with setting emission quotas on the basis of a future year, since this provides no incentive to reduce emissions between now and that date, and, in fact, every incentive to steer toward higher emissions. It might be asked why we did not use an earlier reference date such as 2000. The reason relates to one of the major developing country concerns about contributing to the effort to reduce GHGs—that Annex I countries were able to achieve a high level of industrialization before they undertook the burden of GHG control, and it would be unfair to ask developing countries to do so before they reached a similar level (see, e.g., Agarwal and Narain, 1991). In that regard, the Year 2010 may still be premature.

[8] Asian Tigers include Hong Kong, Singapore, South Korea, and Taiwan.

Rose, 1998). Our emphasis will be on issues of interregional equity and the timing of commitments for developing countries.

Our simulations were performed with a dynamic non-linear programming model consisting of the abatement cost and benefit functions for the 14 countries or country groups listed in Table 2. The empirical base of the model is an extension of that used in Rose and Stevens (1993) in three major ways: 1) an extension to the entire globe and a finer delineation of countries, 2) an updated set of marginal abatement functions, and 3) an updated set of marginal benefit functions. The changes in the benefit functions are especially noteworthy since they are tied to CO_2 concentration levels through the Peck and Teisberg (1994) reduced form climate equations. For a more extensive documentation of the model, the reader is referred to Stevens, Rose, and Liao (1998).

B. Results

The results of selected simulations are presented in Tables 3-9, with a comparative summary of these and other simulations presented in Table 10.[9] The results from Table 3 represent the most basic outcome—fixed Kyoto target emission levels (quotas) without any flexibility that would arise from permit trading over time and space.[10] The results indicate the present

[9] The numerical results are in 1990 constant dollars, discounted to the Year 2010 by an assumed 4% real discount rate. Stating the results in 2010 dollars would require a forecast of inflation between the present and 2010, which would likely be of dubious accuracy. The year 1990 was chosen because it is the base year for several key variables (e.g., emission caps). Adjustment to 1998 dollars would result in figures approximately 25% higher than those presented. Of course, none of these considerations would change the relative differences of outcomes between countries or between different permit trading institutions. Note also, the results are presented for three selected (and in many cases) representative years. A summary table in the concluding section of this paper sums the results of each major simulation over the entire planning horizon for a more proper comparison.

[10] Net benefits are calculated as total benefits minus total abatement costs minus the value of permit transfers. Since a permit sale is a source of revenue, it is given a negative value. Subtraction of a negative number yields a net addition to benefits. A permit purchase is treated as a cost or a net reduction in benefits.

Table 3. Benefits and Cost of CO_2 Mitigation without Permit Trading: Kyoto Target Levels for Annex I Countries and No Mitigation for Developing Countries
(in Year 2010 present discounted value)

Country	Mitigation Benefit			Mitigation Cost			Net Benefit		
(Area)	2010	2020	2035	2010	2020	2035	2010	2020	2035
Africa	2.77	3.96	4.85	0.00	0.00	0.00	2.77	3.96	4.85
Aus/NZ	0.11	0.16	0.19	0.00	0.06	0.22	0.11	0.10	-0.03
Canada	0.19	0.27	0.33	0.21	0.25	0.37	-0.02	0.02	-0.04
China	6.44	9.21	11.28	0.00	0.00	0.00	6.44	9.21	11.28
E-Europe	0.20	0.28	0.35	0.23	0.31	0.50	-0.03	-0.03	-0.15
FSU	0.12	0.17	0.21	0.39	0.88	1.89	-0.27	-0.71	-1.68
India	2.81	4.02	4.92	0.00	0.00	0.00	2.81	4.02	4.92
Japan	0.96	1.37	1.68	0.90	1.26	2.10	0.06	0.11	-0.42
L-America	3.34	4.77	5.84	0.00	0.00	0.00	3.34	4.77	5.84
M-East	3.67	5.24	6.42	0.00	0.00	0.00	3.67	5.24	6.42
Asian Tigers	1.67	2.38	2.91	0.00	0.00	0.00	1.67	2.38	2.91
S-Asia	4.31	6.17	7.55	0.00	0.00	0.00	4.31	6.17	7.55
U.S.	1.63	2.32	2.86	2.62	2.93	4.18	-0.99	-0.61	-1.33
W-Europe	2.26	3.23	3.96	3.30	3.97	6.01	-1.03	-0.74	-2.05
Total	30.47	43.54	53.34	7.65	9.66	15.28	22.82	33.88	38.06

discounted value of the global net benefits of achieving the Kyoto targets are increasingly positive over time even from this basic institutional arrangement. Mitigation costs increase, not because MC_A functions shift, but because emission caps under economic growth conditions require movement to higher points on the functions. Our results are based on the premise that the marginal benefits of GHG abatement increase more rapidly than the marginal costs, owing to the exponentially shaped damage functions associated with radiaoctive forcing.[11]

Note that net benefits are negative for each of the Kyoto signatory groups, though this figure never exceeds $2 billion for any of them until the Year 2035 (in the case of Western Europe). The coexistence of these results with positive global net benefits stems from the fact that the majority of benefits are experienced by developing countries (see especially China and South Asia), who at the same time do not incur the costs of GHG mitigation.

Allowing permit trading improves the situation from both the global and individual country perspective (see Table 4). Gross benefits for each country stay the same, but mitigation costs are lowered for each Annex I country through trading. In the Year 2010, all countries experience positive net benefits except the U.S. and Western Europe, though these countries' net benefit deficit is lower than in the inflexible quota case. Net benefits become negative for other Annex I countries over the time horizon, but they are all still better off than without intercountry permit trading. The U.S., Western Europe, and Japan are the permit buyers in Year 2010, and the other three Annex I groups being the sellers. Approximately $3.1 billion of permits are exchanged. This trading pattern is the same until the 2030s when Australia/ New Zealand become permit buyers. The global gains from trade are $2 billion in the first year (compare the total $24.84 billion in Table 4 with $22.82 billion in Table 3). The gain dips in Year 2020 and then reaches more than $2.5 billion (in constant dollars) in Year 2035.

[11] We realize that this premise is debatable, and again emphasize the importance of the relative results between our simulations rather than the absolute numbers of any simulation itself.

Table 4. Benefits and Costs of CO_2, Mitigation with Interregional Permit Trading among Annex I Countries: Kyoto Target Levels for Annex I Countries and No Mitigation for Developing Countries

(in Year 2010 present discounted value)

Country (Area)	2010						2020			2035		
	Pre-Trading			Post-Trading			Post-Trading			Post-Trading		
	Benefit	Cost	NB	Cost	Permit $	NB	Cost	Permit $	NB	Cost	Permit $	NB
Africa	2.77	0.00	2.77	0.00	0.00	2.77	0.00	0.00	3.96	0.00	0.00	4.85
Aus/NZ	0.11	0.00	0.11	0.08	-0.13	0.16	0.14	-0.08	0.08	0.20	0.02	-0.03
Canada	0.19	0.21	-0.02	0.11	0.08	0.00	0.19	0.11	-0.07	0.26	0.09	-0.03
China	6.44	0.00	6.44	0.00	0.00	6.44	0.00	0.00	9.21	0.00	0.00	11.28
E-Europe	0.20	0.23	-0.03	0.78	-0.73	0.15	1.26	-1.17	0.16	1.62	-1.51	0.23
FSU	0.12	0.39	-0.27	2.00	-2.29	0.41	3.33	-2.95	-0.24	4.49	-3.24	-1.04
India	2.81	0.00	2.81	0.00	0.00	2.81	0.00	0.00	4.02	0.00	0.00	4.92
Japan	0.96	0.90	0.06	0.29	0.43	0.24	0.51	0.74	-0.06	0.73	1.00	-0.05
L-America	3.34	0.00	3.34	0.00	0.00	3.34	0.00	0.00	4.77	0.00	0.00	5.84
M-East	3.67	0.00	3.67	0.00	0.00	3.67	0.00	0.00	5.24	0.00	0.00	6.42
Asian Tigers	1.67	0.00	1.67	0.00	0.00	1.67	0.00	0.00	2.38	0.00	0.00	2.91
S-Asia	4.31	0.00	4.31	0.00	0.00	4.31	0.00	0.00	6.17	0.00	0.00	7.55
U.S.	1.63	2.62	-0.99	1.44	1.01	-0.82	2.42	1.04	-1.43	3.29	0.84	-1.28
W-Europe	2.26	3.30	-1.03	0.92	1.64	-0.29	1.58	2.34	-1.11	2.23	2.81	-1.08
Total	30.47	7.65	22.82	5.63	0.00	24.84	9.42	0.00	33.09	12.82	0.00	40.52

Note: Permit price (real terms and discounted) in selected years:

2010: $25.16/t C
2020: $26.55/t C
2035: $22.81/t C

Permit trading balance in each year equals 0 t C

Banking reaps economic advantages as well, though the results are somewhat difficult to assess from just the three selected years presented in Table 5.[12] They are better illustrated in the present value display for the entire time horizon in Table 10. The reason is that banking (or borrowing) alters the pattern of gross and net benefits over time, thus making year-by-year comparisons with earlier tables difficult. The results presented in Table 5 indicate that all Annex I countries find it advantageous to shift permits to the future in the Year 2010 (negative signs indicate “selling” permits to themselves). This raises net benefits in that year, but lowers them later in the time horizon in comparison to other years for the previous cases examined.[13]

Banking differs from a more flexible interperiod trading institution because it requires a zero or positive permit account balance at all times, whereas full interperiod trading allows individual nations to have a negative permit account balance (borrowing). Although we do not display these results, simulating interperiod trading among Annex I countries shows that taking permits from the future and using them in the present is advantageous, primarily for Canada, Japan, the U.S. and Western Europe. Abatement costs typically decline over the 25 year time horizon for each of these nations, implying that they can reduce present costs by using permits that can be generated more cheaply at a later date. However, the global economic gains from this trading institution, compared to banking only, are modest at best, in part because the reduction in costs affects only a few

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[12] For permit trading institutions in which permit banking or borrowing is allowed, we follow the convention established for permit sales and purchases. A banked permit has a negative value, that is, it is treated as a sale to oneself or to a permit broker, and thus it is an addition to net benefits. The country or group of countries buys the permit back at some future date, when it is treated as a cost.

[13] Note also that interperiod trading results in a constant discounted permit price over the planning period. Again, this represents the intertemporal opportunity cost of utilizing a permit at any given time. The standard arbitrage equation of intertemporal optimization requires that this price be constant, thus ensuring that any potential gains from shifting permits across years have been exhausted.

Table 5. Benefits and Costs of CO_2 Mitigation with Permit Banking for Each Annex I Country: Kyoto Target Levels for Annex I Countries and No Mitigation for Developing Countries
(in Year 2010 present discounted value)

	2010							2020				2035			
Country	Pre-Banking			Post-Banking				Post-Banking				Post-Banking			
(Area)	Benefit	Cost	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB
Africa	2.77	0.00	2.77	2.96	0.00	0.00	2.96	3.96	0.00	0.00	3.96	4.75	0.00	0.00	4.75
Aus/NZ	0.11	0.00	0.11	0.12	0.06	-0.06	0.12	0.16	0.09	-0.01	0.08	0.19	0.14	0.05	0.00
Canada	0.19	0.21	-0.02	0.20	0.21	0.00	-0.01	0.27	0.30	0.00	-0.04	0.32	0.37	0.00	-0.05
China	6.44	0.00	6.44	6.88	0.00	0.00	6.88	9.21	0.00	0.00	9.21	11.05	0.00	0.00	11.05
E-Europe	0.20	0.23	-0.03	0.21	0.27	-0.02	-0.04	0.28	0.37	0.00	-0.09	0.34	0.50	0.00	-0.16
FSU	0.12	0.39	-0.27	0.13	0.81	-0.24	-0.45	0.17	1.11	-0.02	-0.92	0.20	1.61	0.15	-1.56
India	2.81	0.00	2.81	3.00	0.00	0.00	3.00	4.02	0.00	0.00	4.02	4.82	0.00	0.00	4.82
Japan	0.96	0.90	0.06	1.02	1.01	-0.08	0.10	1.37	1.49	0.03	-0.15	1.65	2.10	0.00	-0.46
L-America	3.34	0.00	3.34	3.57	0.00	0.00	3.57	4.78	0.00	0.00	4.78	5.72	0.00	0.00	5.72
M-East	3.67	0.00	3.67	3.92	0.00	0.00	3.92	5.24	0.00	0.00	5.24	6.29	0.00	0.00	6.29
Asian Tigers	1.67	0.00	1.67	1.78	0.00	0.00	1.78	2.38	0.00	0.00	2.38	2.86	0.00	0.00	2.86
S-Asia	4.31	0.00	4.31	4.61	0.00	0.00	4.61	6.17	0.00	0.00	6.17	7.40	0.00	0.00	7.40
U.S.	1.63	2.62	-0.99	1.74	2.63	-0.01	-0.88	2.33	3.57	0.00	-1.24	2.80	4.18	0.00	-1.39
W-Europe	2.26	3.30	-1.03	2.42	3.37	-0.05	-0.91	3.24	4.84	0.00	-1.60	3.88	6.01	0.00	-2.13
Total	30.47	7.65	22.82	32.54	8.36	-0.45	24.63	43.59	11.76	0.01	31.82	52.26	14.92	0.20	37.14

Note: Permit price (real terms and discounted) in all years: Aus/N.Z.: $13.48/t C; Canada: $21.72/t C; E-Europe: $5.92/t C; FSU: $7.36/t C; Japan: $35.13/t C; US: $20.40/t C; W-Europe: $33.57/t C.

Permit banking selected years: 2010: 44 million t C
2020: 2 million t C
2035: -24 million t C

Permit banking balance for Annex I countries: 2010-2035 = 0 t C nations, and each nation's discounted gross benefits are reduced in early time periods and increased in later time periods.

Space limitations also do not allow us to display the full simulation results for the case of both interregional and interperiod trading among Annex I nations. These results are quite interesting in comparison to Table 4, the interregional trading only case. For example, the present discounted value of permits declines to $18.36 per ton of carbon. The decrease in permit prices reduces the value of permits sold by the FSU and increases number (and hence the value of permits purchased by large buyers (both interregion and interperiod) such as the U.S. and Western Europe. The opportunity to borrow permits from the future brings down the price of permits, thereby improving the net benefits of buyers and diminishes it for sellers, even though, for example, the FSU sells about 100,000 more tons of carbon (in comparison to the results in Table 4) both 2010 and 2035. Globally, net benefits are higher by about $.5 to $1 billion dollars annually.

The results of the inclusion of developing countries into permit trading are extremely interesting as presented in Table 6. Global gains and net benefits become quite large, reaching more than $50 billion in 2035, a $12 billion increase over the base case in Table 3. Interestingly, however, some Annex I countries stand to be worse off from the admission of developing countries in comparison to the counterpart Annex I only case (Table 5), since they lose their comparative advantage in permit selling. For example, Eastern Europe and the former Soviet Union now for the most part become permit buyers rather than permit sellers. They still are better off than under the inflexible quota system; however, their gains from lower mitigation costs are not as high as their now forgone gains from permit selling. Still, this should not overshadow the large global gains. Essentially net benefits are increased dramatically by bringing development countries (DCs) into the permit trading process. At the same time, DCs can gain experience in permit trading at "No Harm" to themselves, i.e., they can choose not to sell any permits if they are apprehensive. However, they will eventually realize that some permits can be sold safely with a net gain to themselves.

Table 6. Benefits and Costs of CO_2 Mitigation with Interregional Permit Trading among Annex I Countries and Developing Countries: Kyoto Target Levels for Annex I Countries and No Harm for Developing Countries
(in Year 2010 present discounted value)

Country	2010							2020				2035			
	Pre-Trading			Post- Trading				Post- Trading				Post- Trading			
(Area)	Benefit	Cost	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB
Africa	2.77	0.00	2.77	2.77	0.11	-0.22	2.88	3.96	0.18	-0.37	4.15	4.85	0.24	-0.48	5.09
Aus/NZ	0.11	0.00	0.11	0.11	0.02	-0.02	0.12	0.14	0.02	0.04	0.08	0.19	0.01	0.08	0.10
Canada	0.19	0.21	-0.02	0.19	0.02	0.09	0.07	0.23	0.03	0.12	0.08	0.33	0.02	0.12	0.19
China	6.44	0.00	6.44	6.44	0.30	-0.60	6.74	9.21	0.42	-0.85	9.64	11.28	0.40	-0.81	11.69
E-Europe	0.20	0.23	-0.03	0.20	0.16	0.07	-0.03	0.24	0.18	0.16	-0.10	0.35	0.13	0.24	-0.03
FSU	0.12	0.39	-0.27	0.12	0.39	-0.01	-0.27	0.15	0.46	0.48	-0.80	0.21	0.33	0.90	-1.02
India	2.81	0.00	2.81	2.81	0.10	-0.20	2.91	4.02	0.15	-0.31	4.18	4.92	0.18	-0.36	5.11
Japan	0.96	0.90	0.06	0.96	0.06	0.33	0.57	1.19	0.07	0.49	0.63	1.68	0.05	0.52	1.11
L-America	3.34	0.00	3.34	3.34	0.29	-0.60	3.65	4.77	0.43	-0.90	5.24	5.84	0.45	-0.93	6.33
M-East	3.67	0.00	3.67	3.67	0.31	-0.65	4.00	5.24	0.49	-1.02	5.77	6.42	0.55	-1.15	7.02
Asian Tigers	1.67	0.00	1.67	1.67	0.04	-0.09	1.71	2.38	0.07	-0.14	2.45	2.91	0.07	-0.15	2.99
S-Asia	4.31	0.00	4.31	4.31	0.19	-0.39	4.51	6.17	0.34	-0.70	6.53	7.55	0.46	-0.95	8.05
U.S.	1.63	2.62	-0.99	1.63	0.27	1.13	0.23	2.02	0.32	1.47	0.24	2.86	0.22	1.44	1.19
W-Europe	2.26	3.30	-1.03	2.26	0.17	1.15	0.94	2.80	0.21	1.54	1.06	3.96	0.15	1.53	2.28
Total	30.47	7.65	22.82	30.47	2.43	0.00	28.04	42.51	3.36	0.00	39.15	53.34	3.25	0.00	50.09

Note: Permit price (real terms and discounted) in selected years:
2010: $10.79/t C
2020: $9.35/t C
2035: $5.63/t C
Permit trading balance in each year equals 0 t C

Table 7. Benefits and Costs of CO_2 Mitigation with Interperiod and Interregional Permit Trading among Annex I Countries and Developing Countries: Kyoto Target Levels for Annex I Countries and No Harm for Developing Countries
(in Year 2010 present discounted value)

Country	2010							2020				2035			
	Pre- Trading			Post- Trading				Post- Trading				Post- Trading			
(Area)	Benefit	Cost	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB
Africa	2.77	0.00	2.77	3.29	0.18	-0.76	3.87	4.20	0.22	-1.30	5.27	4.07	0.14	-1.97	5.90
Aus/NZ	0.11	0.00	0.11	0.13	0.03	-0.08	0.18	0.17	0.02	0.11	0.04	0.16	0.01	0.46	-0.30
Canada	0.19	0.21	-0.02	0.22	0.04	0.21	-0.03	0.28	0.03	0.37	-0.12	0.27	0.01	0.68	-0.42
China	6.44	0.00	6.44	7.65	0.48	-2.10	9.26	9.77	0.50	-2.95	12.22	9.47	0.24	-3.35	12.58
E-Europe	0.20	0.23	-0.03	0.23	0.26	-0.06	0.03	0.30	0.22	0.39	-0.31	0.29	0.08	1.58	-1.38
FSU	0.12	0.39	-0.27	0.14	0.64	-0.61	0.11	0.18	0.55	1.25	-1.62	0.17	0.20	5.52	-5.54
India	2.81	0.00	2.81	3.34	0.16	-0.69	3.87	4.27	0.19	-1.09	5.17	4.14	0.11	-1.47	5.50
Japan	0.96	0.90	0.06	1.14	0.09	0.82	0.22	1.45	0.08	1.52	-0.14	1.41	0.03	2.85	-1.47
L-America	3.34	0.00	3.34	3.96	0.47	-2.09	5.58	5.06	0.52	-3.10	7.65	4.91	0.28	-3.90	8.53
M-East	3.67	0.00	3.67	4.35	0.50	-2.24	6.09	5.56	0.58	-3.51	8.50	5.39	0.34	-4.86	9.91
Asian Tigers	1.67	0.00	1.67	1.98	0.07	-0.31	2.22	2.53	0.08	-0.48	2.92	2.45	0.04	-0.61	3.01
S-Asia	4.31	0.00	4.31	5.12	0.31	-1.35	6.17	6.54	0.40	-2.40	8.55	6.35	0.28	-3.97	10.03
U.S.	1.63	2.62	-0.99	1.94	0.45	2.69	-1.20	2.47	0.38	4.46	-2.37	2.40	0.14	8.13	-5.86
W-Europe	2.26	3.30	-1.03	2.69	0.29	2.88	-0.48	3.43	0.25	4.77	-1.58	3.33	0.09	8.41	-5.17
Total	30.47	7.65	22.82	36.18	3.96	-3.67	35.90	46.21	4.01	-1.97	44.17	44.81	1.99	7.50	35.31

Note: Permit price (real terms and discounted) in all years: $29.68/t C;
Permit trading selected years: 2010: -124 million t C
2020: -66 million t C
2035: 253 million t C
Permit trading balance: 2010-2035 = 0 t C

Table 8. Benefits and Costs of CO_2 Mitigation with Interperiod and Interregional Permit Trading among Annex I Countries and Developing Countries: Kyoto Target Levels for Annex I Countries and All Developing Countries Commit to Quotas based on Year 2020 Emissions, Sovereignty Criterion Allocation vs. Egalitarian Allocation for Developing Countries

(in Year 2010 present discounted value)

Country	Sovereignty 2035				Egalitarian 2035			
	Post- Trading				Post- Trading			
(Area)	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB
Africa	7.02	0.82	2.60	3.61	7.02	0.82	0.47	5.74
Aus/NZ	0.28	0.05	0.12	0.11	0.28	0.05	0.12	0.11
Canada	0.47	0.06	0.19	0.22	0.47	0.06	0.19	0.22
China	16.34	1.39	4.43	10.52	16.34	1.39	5.45	9.49
E-Europe	0.50	0.45	0.05	0.00	0.50	0.45	0.05	0.00
FSU	0.30	1.16	0.69	-1.55	0.30	1.16	0.69	-1.55
India	7.14	0.61	1.94	4.59	7.14	0.61	-1.68	8.20
Japan	2.43	0.18	0.90	1.36	2.43	0.18	0.90	1.36
L-America	8.47	1.45	0.61	6.41	8.47	1.45	1.95	5.07
M-East	9.30	1.69	-0.23	7.83	9.30	1.69	2.02	5.59
Asian Tigers	4.22	0.26	1.24	2.73	4.22	0.26	3.35	0.62
S-Asia	10.95	1.48	0.62	8.85	10.95	1.48	-0.36	9.83
U.S.	4.14	0.80	2.18	1.16	4.14	0.80	2.18	1.16
W-Europe	5.74	0.54	2.63	2.57	5.74	0.54	2.63	2.57
Total	77.30	10.92	17.95	48.42	77.30	10.92	17.95	48.42

Note: Permit price (real terms and discounted) in all years: $11.73/t C;
Permit trading selected years: 2010: -471 million t C
2020: -640 million t C
2035: 1,531 million t C
Permit trading balance: 2010-2035 = 0 t C

Table 7 illustrates the simulation results for interregional and interperiod trading among the Annex I and developing nations. Net benefits for nations such as the U.S. and the FSU are lower for all three years, and higher for nations and regions such as China and Latin America, in comparison to previous results. For example, China's net benefits increase by $2.52 billion and $1.4 billion in 2010 and 2035, while and Latin America's net benefits are greater by $1.93 and $2.79 billion, respectively. Globally, net benefits are greater in 2010 and 2020, though they are lower in 2035.

Table 8 shows simulation results in 2035 from two different distributions of permits to developing countries, based on Year 2020 emission cap for these countries as a whole, while Annex I countries continue to meet the Kyoto targets. The Sovereignty equity criterion distributes permits to developing nations such that each nation's percentage reduction in greenhouse gases is equal to the percentage reduction of the entire group of developing nations. The Egalitarian equity criterion distributes the stock of permits available to the developing nations according to relative population shares after 2020. Table 8 shows that countries or regions with relatively high population growth rates, such as Africa (3% population growth) are better off relative to regions such as Latin America (1.8% growth) or the Asian Tigers (.4% growth). For example, Latin America's net benefits are lower by $1.34 billion in 2035 under the Egalitarian allocation than under the Sovereignty allocation. Since equilibrium abatement costs are unaffected by different permit distributions (recall the Coase Theorem), all of the decline is due to Latin America's smaller initial permit holdings and the subsequent increase in the purchase of permits.

The timing of greenhouse gas abatement commitments for non-Annex I countries is a potentially contentious issue. Table 9 shows simulation results from a case in which the Middle East, the Asian Tigers and Latin America, all countries with per capita incomes exceeding $1,000 per year, are brought into a greenhouse permits market in 2010 with permit allocations equivalent to emissions in 2010. The remaining developing nations are brought into the permits market in 2020, with initial permit allocations equal to emissions

Table 9. Benefits and Costs of CO_2 Mitigation with Interperiod and Interregional Permit Trading among Annex I Countries and Developing Countries: Kyoto Target Levels for Annex I Countries, Group A Countries Commit to Quotas based on Year 2010 Emissions and Group B Countries Commit to Quotas based on Year 2020 Emisions

(in Year 2010 present discounted value)

Country	2010							2020				2035			
	Pre- Trading			Post- Trading				Post- Trading				Post- Trading			
(Area)	Benefit	Cost	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB	Benefit	Cost	Permit $	NB
Africa	2.77	0.00	2.77	4.93	0.61	-0.27	4.59	6.58	0.95	-0.51	6.15	7.95	1.30	1.46	5.19
Aus/NZ	0.11	0.00	0.11	0.20	0.09	-0.03	0.14	0.26	0.10	-0.01	0.17	0.32	0.08	0.05	0.20
Canada	0.19	0.21	-0.02	0.33	0.13	0.02	0.19	0.44	0.13	0.04	0.27	0.53	0.10	0.08	0.36
China	6.44	0.00	6.44	11.47	1.69	-0.75	10.54	15.32	2.15	-1.17	14.34	18.49	2.21	0.95	15.33
E-Europe	0.20	0.23	-0.03	0.35	0.87	-0.19	-0.33	0.47	0.91	-0.17	-0.26	0.57	0.70	-0.09	-0.04
FSU	0.12	0.39	-0.27	0.21	2.24	-0.58	-1.45	0.28	2.37	-0.41	-1.67	0.34	1.83	0.02	-1.52
India	2.81	0.00	2.81	5.01	0.55	-0.25	4.70	6.69	0.79	-0.43	6.33	8.08	0.97	0.85	6.27
Japan	0.96	0.90	0.06	1.71	0.33	0.09	1.29	2.28	0.36	0.20	1.73	2.75	0.28	0.39	2.08
L-America	3.34	0.00	3.34	5.94	1.54	-0.71	5.12	7.94	2.01	-0.35	6.27	9.58	2.20	0.57	6.81
M-East	3.67	0.00	3.67	6.53	1.56	-0.74	5.71	8.72	2.13	-0.44	7.03	10.53	2.51	0.38	7.63
Asian Tigers	1.67	0.00	1.67	2.96	0.26	-0.11	2.82	3.96	0.36	0.18	3.42	4.78	0.41	0.87	3.50
S-Asia	4.31	0.00	4.31	7.68	0.99	-0.46	7.15	10.26	1.56	-0.89	9.59	12.39	2.24	0.49	9.66
U.S.	1.63	2.62	-0.99	2.91	1.62	0.19	1.10	3.88	1.69	0.40	1.79	4.69	1.29	0.85	2.55
W-Europe	2.26	3.30	-1.03	4.03	1.03	0.35	2.65	5.38	1.11	0.62	3.65	6.50	0.87	1.14	4.49
Total	30.47	7.65	22.82	54.25	13.49	-3.45	44.21	72.46	16.60	-2.95	58.82	87.49	16.97	8.00	62.51

Note: Permit price (real terms and discounted) in all years: $5.78/t C;
Permit trading selected years: 2010: -597 million t C
2020: -510 million t C
2035: 1,383 million t C
Permit trading balance: 2010-2035 = 0 t C

in 2020. Interregional and interperiod permit trading are allowed. One immediate result from this global agreement is that it increases the global supply of permits, relative to those cases where all developing nations are brought into the permits market in 2020 because the countries that enter the permit market have greater emissions in 2020 than in 2010. The increased permit supply drives permit prices down, and globally net benefits rise. In comparison to Table 7, which differs only by the timing of greenhouse commitments, net benefits for Latin America and the Middle East are lower in 2010, 2020 and 2035, with the disparity the largest in 2035. For example, Latin America's net benefits are reduced by $1.72 billion and the Middle East is worse off by $2.28 billion. The Asian Tigers would experience an increase in net benefits, for example, in 2035, net benefits would rise by $.49 billion.

Our final policy simulation—incorporation of an intergenerational equity criterion—did not yield a feasible solution. This is due to a combination of factors affecting Eastern Europe and the former Soviet Union, which are such that it is impossible for these regions to achieve positive net benefits for every year of the planning horizon. The factors include the stringency of emission reduction requirements, low level of benefits, and high level of costs relative to those of other countries/regions. It appears that if a strict definition of intergenerational equity is imposed, it would be necessary to provide some relief from the Kyoto emission caps for these countries or to provide them with cash transfers.

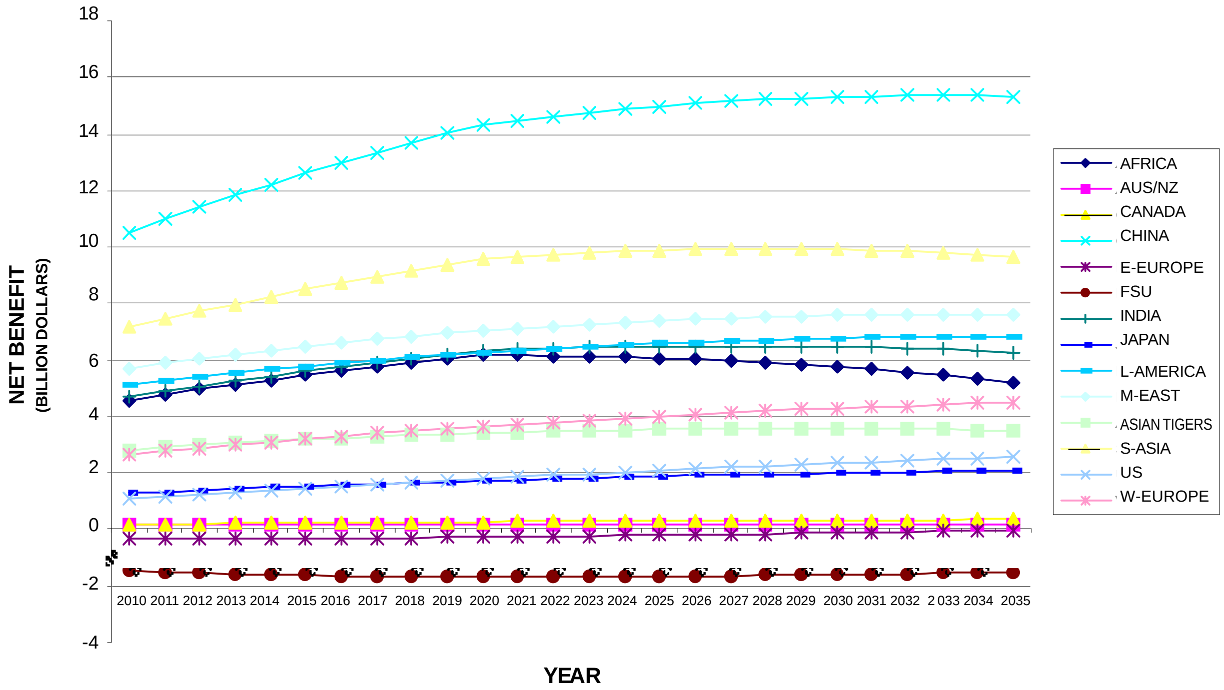
Figure 1 shows net benefits for each nation or region over the model time horizon for the simulation in Table 10. Though net benefits are negative for the FSU and Eastern European nations from 2010 to 2035, other countries would experience positive net benefits. For regions such as Africa, Southeast Asia, and India, net benefits begin declining as early as 2024. All of these regions are initially permit sellers whose sales decline over time, until eventually these countries become permit buyers. This effect outweighs the increase in gross benefits from rising greenhouse gas abatement, thus their net benefits eventually begin to decline in later periods.

Table 10. Summary of Permit Trading Simulations, 2010 to 2035[a]

Country (Area)	Kyoto (Fixed Quotas for Annex I)	Kyoto+ Interregional (Annex I Only)	Kyoto+ Interperiod (Annex I Only)	Kyoto Interregional All (No Harm for for DCs)	Kyoto + Timing + All DCs 2020 (Sovereignty)	Kyoto + Timing + All DCs 2020 (Egalitarian)	Kyoto + Timing (Group A 2010 Group B 2020)
Africa	104.00	104.79	104.73	109.17	137.13	166.05	146.92
Aus/NZ	1.49	1.77	1.66	2.71	4.05	4.05	4.54
Canada	-0.94	-0.58	-0.91	3.61	5.48	5.48	7.38
China	241.96	243.78	243.64	252.85	329.98	308.99	364.30
E-Europe	-2.70	4.81	-2.68	-1.02	-0.52	-0.52	-5.59
FSU	-26.95	-10.95	-26.69	-19.68	-28.11	-28.11	-41.73
India	105.68	106.47	106.41	110.00	144.70	201.56	157.58
Japan	-5.31	2.70	-5.28	23.18	34.86	34.86	45.87
L-America	125.39	126.34	126.27	136.40	182.65	160.49	163.25
M-East	137.72	138.76	138.69	150.65	207.58	171.73	182.80
Asian Tigers	62.54	63.01	62.98	64.53	85.21	53.65	87.85
S-Asia	162.08	163.31	163.21	171.86	238.12	262.89	240.33
U.S.	-32.38	-28.68	-31.63	20.16	31.01	31.01	49.43
W-Europe	-43.40	-18.12	-42.61	44.93	67.58	67.58	97.39
Global NB	829.18	897.41	837.79	1069.33	1439.73	1439.73	1500.32
Incremental NB Increase	—	68.23	-59.63	231.55	370.40	0.00	60.60
Cumulative NB Increase	—	68.23	8.60	240.15	610.54	610.54	671.14

[a] In present discounted value terms summed over the entire time horizon 2010-2035 (4% discount rate).

Figure 1. Net Benefit of CO_2 Mitigation: Kyoto Target Levels for Annex 1 Countries, Group A Countries Commit to Quotas based on Year 2010 Emissions and Group B Countries to Quotas based on Year 2020 Emissions



V. Conclusion

The marketable permits approach to global warming policy can have many variants depending on the number of countries included, whether permits can be traded over time, the timing of mitigation commitments themselves, and the manner in which the permits are distributed among countries. The latter two features address equity head on, although the first two features, usually motivated by efficiency gains, have equity implications as well. This is important from a normative standpoint but also in regard to the political viability of any greenhouse gas treaty proposal.

Table 10, which summarizes our main simulations, illustrates these points. Comparisons are facilitated by the fact that net benefits are summarized over the entire policy time horizon rather than the previous presentations of just three selected (and sometimes unrepresentative) years.

Even if trading is limited only to Annex I countries, global net benefits rise because trading reduces the cost of meeting the Kyoto targets. Interestingly, modifying the permits institution to allow trading across Annex I countries and across time is also better than a system of fixed quotas but diminishes global net benefits compared to interregional trading only. The reason is that several countries find it personally advantageous to defer emission reductions to a later date, thereby reducing near-term benefits to everyone else.

Much larger gains from interregional permit trading are available if developing nations are granted transferable permits in an amount equivalent to their emissions in 2010 (and subsequent years). The developing nations are made no worse off, even if they choose not to sell any of their permits, and they gain the opportunity to profit from permit sales from ready trading partners among the Annex I nations. These incremental gains are $231 billion over the model time horizon, again due to the reduction in abatement costs among the industrialized nations.

The two simulations for different permit distributions according to Sovereignty and Egalitarian equity rules indicate another large global gain due primarily to requiring developing countries to commit to GHG emission targets before the end of the policy horizon, and at the same time delaying their entrance into the permits market (the simulation does not include the No Harm option from 2010 to 2020). These simulations differ from the Kyoto interregional trading case in that we have also incorporated interperiod permit trading. However, this factor alone accounts for little more than a $5 billion incremental increase in net benefits; hence, the inclusion of developing country mitigation commitments is responsible for most of the incremental gain of $370 billion. Obtaining these commitments, even though delaying the entrance of developing nations into the permits market, effectively reduces the total supply of permits over the model time horizon by 10 years worth of emissions from these countries. The ensuing abatement increases benefits more than it increases costs in comparison to the previous cases. We did not investigate whether delaying entrance of the developing nations until later years would have a similar effect on global net benefits, but there is every indication from our data that it would.

Finally, there is a slight gain of $61 billion in securing commitments from Latin America, the Middle East, and the Asian Tigers in 2010 instead of 2020. We take this to imply that, while it is important to consider the timing of including developing nations in a greenhouse protocol, fine-tuning the dates among non-Annex I nations may only result in small increase in global net benefits. The reason is that the Group A developing countries (those with per capita incomes exceeding $1,000) have relatively high abatement cost functions.

In summary, the greatest efficiency gains in the design of a GHG tradeable permit policy stem from utilizing the low-cost mitigation options of developing countries (even if no additional mitigation is forthcoming from this group itself) and then from requiring emission reductions from developing countries at some future date. Interestingly, interperiod permit trading (banking or borrowing) yields relatively small incremental gains. The first of the more worthwhile extensions of the Kyoto accord are consistent with many nations' conception of equity at present (i.e., "No Harm" rule), while the second is likely to become embroiled in some equity controversies, which will be decided to a great extent on the basis of the timing of these additional commitments.

We have also uncovered two ironies in the dynamic context. The first relates to the fact that a given country acting in pursuit of its own objectives might shift its mitigation temporally so as to lower net benefits to other countries. Also, net benefits could be increased more by having the poorest developing countries commit to emission caps first, since they have relatively lower mitigation costs and higher mitigation benefits, and then later including the top tier of countries, such as Latin America and the Asian Tigers. However, equity considerations are likely to override such a timing decision.

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