“Financing Global Environmental Programs: Efficient Approaches to Cooperation and Institutional Design”

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Financing Global Environmental Programs: 
Efficient Approaches to Cooperation and Institutional Design

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Abstract

This paper addresses several issues related to global cooperation and international resource transfer for reducing greenhouse gas (GHG) emissions to mitigate global climate change, currently an area of significant academic and policy interest. Global environmental projects are quite unique because their benefits are shared globally, whereas investments have to be undertaken by the countries in which the projects are located. We develop an economic framework built around a group of countries or country groups with heterogeneous preferences and incomes to evaluate opportunities for efficiency gains through international resource transfers and to assess alternative institutional mechanisms for effecting these transfers. To illustrate this framework, we identify its parameters for 1989 data and use it to simulate the outcomes associated with various levels of international cooperation and resource transfers.

Our analysis clearly demonstrates that because of differences in project marginal benefits and country preferences, cross-border investments (e.g. by OECD countries in GHG abatement projects located in developing countries) can create significant win-win situations from the standpoint of all countries -- i.e. those who fund and those who host investments -- relative to more autarkic outcomes where all such investments are carried out by the individual countries concerned. Thus, rather than seeing a tradeoff between equity and efficiency, as is sometimes argued in the economics literature, we argue that, in the present context, these two welfare criteria are mutually reinforcing. The focus of transfers is clearly to promote efficiency through targeted project funding. But the process of identifying, implementing and monitoring optimal project funding opportunities requires cooperation from the countries in which projects are located. Obtaining this cooperation, together with a commitment to GHG mitigation targets and funding procedures, will require a sense of perceived fairness or equity in the burdens and benefits associated with these targets and procedures. Absent this sense of equity, only a range of noncooperative outcomes become possible for the global coalition. To the extent that such noncooperative outcomes entail efficiency losses, maintaining a sense of perceived equity is efficiency enhancing.

The success of a global environmental investment program depends critically on the institutional mechanism that is employed for implementing it. We compare and contrast multilateral (e.g. through a Global Environmental Fund) and bilateral (i.e. joint implementation) schemes. A critical feature that differentiates these schemes is the allocation of the surplus associated with individual investments between the investing countries (and by extension the global community) and the host country. The global environmental fund as it's currently constituted pays out incremental costs to the host countries, thereby capturing the entire project surplus for the global community. As is evident from the recent track record of the GEF, this dampens incentives for project selection and their speedy implementation, while also increasing the transactions costs expended by the global community. We examine more decentralized and market-oriented approaches, both bilateral and multilateral, which through the allocation of part of the surplus to host countries, have the potential to resolve these problems and considerably speed up the implementation of global environmental projects.

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1. Introduction

Growing awareness and increasing concern about the accumulation of greenhouse gases (GHGs) has led to a series of initiatives -- such as the United Nations Framework Convention on Climate Change (FCCC), and the Rio de Janeiro Conference in 1992 -- towards a global accord on the mitigation of global climate change. Modest progress was achieved in the international arena during the first conference of parties to the FCCC held in Berlin, in March-April 1995. First, delegates agreed to start a negotiating process to be concluded in 1997, that would set "limitation and reduction objectives" for all greenhouse gases within a specified future timeframe, for Annex I countries (basically OECD and transition economies). There would be no new commitments for developing countries. Second, joint implementation or JI activities (involving coordinated GHG reductions between two countries) would be tested during a pilot phase, and then revised by the year 2000. While all countries could participate, Annex I countries would not receive any credit for GHG reductions achieved through JI activities during this pilot phase.

As in the case of the Montreal Protocol for the elimination of CFCs, an important issue associated with such the FCCC is the allocation of resources globally to achieve this mitigation in the most efficient and equitable manner. This paper identifies several issues relating to the design of institutions to implement economically efficient and equitable approaches to monitoring and mitigating the effects of Greenhouse Gases (GHGs), especially carbon dioxide, on the global environment and the global economy.

A key difference between the reduction of carbon dioxide and the reduction of ozone depleting substances is that production of the latter was concentrated in the industrialized world and a few large developing nations, whereas the production of other greenhouse gases is widely dispersed and is rising...
rapidly in the developing world due to the heavy use of fossil fuels and forest depletion. Hence, whereas resource transfers envisaged in the Montreal Protocol were primarily driven by equity considerations and aimed at offsetting the cost of changes on the demand side, it is clear that from an efficiency standpoint, achieving global GHG reduction targets would require substantial investments to reduce the emission of GHGs in the developing world. It is also clear that the sheer magnitude of the economic impacts likely to be under discussion will be considerably higher, so that the consequences of policies, including those directed at equitable burden sharing, will not be just “at the margin”, but will entail significant changes in business as usual scenarios. Furthermore, the science of global climate change is fraught with uncertainties, so that issues of monitoring and mitigation and the impact of policy on these will be much more difficult to understand. Coupled with scientific uncertainty are issues of policy uncertainty related to available data, especially in LDCs, on levels of economic activity in sectors using or generating GHGs. This is partially the result of very diffuse sources and sinks for GHGs and the very large number of economic agents involved in these sectors. The forthcoming second report of the inter-governmental panel on climate change (IPCC) will help to achieve greater scientific consensus on both the physical and socioeconomic parameters of global climate change.

The bulk of this paper is focused on the development of an economic framework to both inform the design of and to evaluate alternative institutional mechanisms for global GHG abatement. This framework is built around a group of countries or country groups with heterogeneous preferences and incomes. We investigate alternative outcomes when countries carry on with “business-as-usual”, (non-cooperatively) maximizing their individual welfare, allocating resources for consumption and GHG-reducing investment accordingly, and when they cooperate in global efforts to mitigate global climate change. Our focus is on seeking out opportunities for cooperation through international resource transfers and the re-allocation of these resources such that all countries are made better off through cooperation. More so than in the case of
the Montreal Protocol, an important element of a cooperative global solution to the GHG problem is the seeking out of projects that are the most efficient from a global standpoint, and ensuring that these projects are implemented through international resource transfers. Thus, for example, the OECD countries might find it more cost effective to invest in GHG abatement projects in developing countries, and fund a pool of resources to put such a program into effect. On the other hand, as in the case of the Montreal Protocol, transfers also play an important role on the equity dimension, since they are an important lubricant for cooperation. The framework that we develop provides a useful basis for examining alternative equity-driven “constraints” on a purely economic solution. Several of these constraints are examined in the paper.

We proceed as follows. The next section develops the basic economic model of this paper, a two-stage model in which countries or regions are assumed to make investments (in GHG mitigation) and monetary transfers in stage 1, before an uncertain state of the world is revealed in stage 2. We contrast two cases: (1) the autarkic case in which transfers are restricted to zero; and (2) the first-best case in which investment resources are pooled and re-allocated globally, to demonstrate the impacts of cooperation. In Section 3, we use the conceptual framework developed in Section 2 to develop a simulation model to illustrate the impact of alternative proposals for cooperation and burden-sharing in mitigating global climate change. In Section 4, we discuss institutional mechanisms for implementing global cooperation, focusing on features of bilateral and multilateral schemes that have been proposed. A final section presents concluding remarks and policy implications, and discusses directions for future research.
2. Modeling International Cooperation for Efficient GHG Mitigation

Investments

In Sections 2 and 3, we investigate impacts of alternate levels of cooperation (as manifested by resource transfers and schemes of burden sharing) on the efficiency of GHG mitigating investments and develop a simulation framework to illustrate impacts on a regional basis. In this section, we develop our conceptual economic framework which enables us to compare and contrast these alternative schemes and their outcomes. In Section 3 we examine the particulars of resource transfers under different constraints through an illustrative simulation framework.

2.1 The Basic Economic Model

We begin by developing in this section a two-stage model of global interactions associated with reducing GHG emissions. Each country faces a number of tradeoffs in confronting the issues of global climate change. The essential features of the model are as follows. First, we reflect the consequences of global GHG emissions and the uncertainty of global climate change on each country. These effects may be quite different from one country to the next. Second, we reflect the cost of investments in technologies or activities directed toward reducing GHG emissions by the country. Resources used for this purpose could clearly be devoted to other productive purposes in the country and the economic consequences of diverting their use to reducing GHG emissions is reflected in the model as a reduction in current consumption.
Let the "GHG production function" for country $\theta$, $g(x(\theta), y(\theta); \theta)$, denote the total GHGs (measured in units of global climate change potential) generated by country $\theta$ in stage 1, and let the total GHGs generated in all countries be denoted by $G(X, Y)$ so that

$$G(X, Y) = \sum_{\theta \in \Theta} g(x(\theta), y(\theta); \theta)$$

(1)

where $\theta$ is the country index and the set of all countries is denoted $\Theta$, $x(\theta)$ is investment by country $\theta$ to reduce GHG emissions at stage 1, $y(\theta)$ is consumption by country $\theta$ at stage 1, $X$ is the vector of all country investments $\{x(\theta) | \theta \in \Theta\}$, and $Y$ is the vector of all country consumptions $\{y(\theta) | \theta \in \Theta\}$. We assume throughout that, for each $\theta$, $g(x, y; \theta)$ is increasing in consumption and decreasing in mitigation investments, i.e., $g_x < 0, g_y > 0$. We also assume that $g(\cdot; \theta)$ is jointly convex in $(x, y)$, so that investments, $x$, have a declining marginal impact on (reducing) $G$ and consumption has an increasing marginal impact on $G$.

We assume the following aggregate welfare function, denoted $U(\theta)$, for country $\theta$:

$$U(X, Y, \omega; \theta) = V(G(X, Y), y(\theta), \omega; \theta), \quad \theta \in \Theta$$

(2)

where $\omega \in \mathcal{X}$ is an uncertain state of the world and $U$ depends on $X$ only through aggregate GHG emissions $G$. We will assume that $V$ is decreasing in $G$, increasing in $y$ and jointly concave in $G$ and $y$.

Given these assumed properties of $G$ and $V$, it is straightforward to show that, for each $\omega$ and $\theta$, $V$ is concave in $(X, Y)$, from which it follows that, for each $\theta \in \Theta$, the expected value of $V$ over $\omega$ is concave in $(X, Y)$.
We will also be interested in characterizing the Pareto-efficient outcomes to the collective
consumption-investment problem associated with the above country welfare functions $U(\theta)$. The set of
Pareto (or first-best) outcomes is important both as an efficiency benchmark as well as in understanding
various "cooperative" solutions, described more fully below, to the global problem of GHG mitigation.

For this purpose, we will define a (weighted utilitarian) global welfare function $W$ as

$$W(X, Y) = E_\omega \left\{ \sum_{\theta \in \Theta} \eta(\theta) U(X, Y, \omega, \theta) \right\} \quad (3)$$

where $F(\omega)$ is the probability distribution on the states of the world, $E_\omega$ is the expectation at stage 1 with
respect to the distribution $F(\omega)$, and $\eta(\theta)$ satisfy:

$$\eta(\theta) \geq 0; \quad \sum_{\theta \in \Theta} \eta(\theta) = 1. \quad (4)$$

Since, as noted, the expected utility functions $E[V(\cdot; \theta)]$ are concave, the Pareto set of allocations from any
convex feasible set are given by the argmax $W_\eta$ as the weights $\{\eta(\theta) \mid \theta \in \Theta\}$ vary over the feasible set
defined by (4). \(^2\)

$U$ may be thought of as the net economic benefits realized from the country’s activities in stages 1
and 2. We assume that investments $x(\theta)$ in GHG reduction and consumption $y(\theta)$ are related by the
following budget constraint:

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\[ l(\theta) = x(\theta) + y(\theta) - s(\theta) \]  \hspace{1cm} (5)

where \( l(\theta) \) is income for country \( \theta \) in stage 1, \( s(\theta) \) is a monetary transfer payment to country \( \theta \) at stage 1, and \( S = \{ s(\theta) | \theta \in \Theta \} \) is the vector of all ex ante transfers.

Thus, investments in GHG reduction will necessarily reduce consumption \( y(\theta) \) unless offset by transfers \( s(\theta) > 0 \) to \( \theta \) from other countries.\(^1\) For feasibility, we require the following restrictions on transfers among countries:

\[ \sum_{\theta \in \Theta} s(\theta) = 0. \]  \hspace{1cm} (6)

**2.2 The Benchmark Noncooperative Outcome**

As noted above, we develop here the benchmark noncooperative outcome based on uncoordinated actions by individual countries. To characterize this noncooperative solution, we use the Nash equilibrium concept for the associated game in which each country attempts to maximize (2) subject to (5), with \( s(\theta) = 0 \). The problem in this case for country \( \theta \) will be:

\[ \text{Maximize} \quad E_{\omega} \left\{ V(G(X,Y), y(\theta), \omega; \theta) \right\} \]  \hspace{1cm} (7)

subject to:

\[ l(\theta) = x(\theta) + y(\theta). \]  \hspace{1cm} (8)
Substituting (8) into (7), country $\theta$ is assumed to solve the following problem, taking other country decisions as given:

$$\text{Maximize } E_0 \left\{ V(G(X, I - X), Y(\theta), X(\theta); \omega, \theta) \right\}$$

Thus, the following first-order conditions characterize the Nash noncooperative equilibrium$^4$:

$$x(\theta) \frac{\partial E[V(\theta)]}{\partial x(\theta)} = 0;$$

$$\frac{\partial E[V(\theta)]}{\partial x(\theta)} = E_0 \left\{ \left[ g_x(\theta) + g_{y}(\theta) \right] V_x(\theta) + V_{x\theta}(\theta) \right\} \leq 0; \quad \forall \theta \in \Theta.$$

2.3 A First-Best Framework for Characterizing Cooperative Outcomes

By a first-best solution, we mean a Pareto allocation $(X, Y, S)$ for the above country welfare functions and constraints, i.e. a solution which cannot be improved upon for all countries simultaneously. From the above, the Pareto solutions $(X, Y)$ must be solutions to the following problem for some feasible weighting vector $\{\eta(\theta) | \theta \in \Theta\}$:

$$\text{Maximize } E_0 \left\{ \sum_{\theta \in \Theta} \eta(\theta) V(G(X, Y), Y(\theta); \omega, \theta) \right\}$$
subject to (5)-(6), where $E_\omega$ is the expectation at stage 1 with respect to the distribution $F(\omega)$. Thus, the first-best solution is effected by putting all resources in the hands of a central global authority, which is assumed to solve (11) with no transactions costs.

Since (5) holds as an equality at the solution to (11), we may eliminate $y(\theta)$ by substituting (5) into (11). The resulting problem of interest is then:

$$\max_{X,\lambda} \quad E_\omega \left\{ \sum_{\eta(\theta)} \left[ V(G|X, I - X + S, \lambda(\theta)) - x(\theta) + s(\theta, \omega, \theta) \right] \right\}$$

(12)

subject to (6). From the Lagrangian $L^C$ for this problem we obtain the following first-order conditions:

$$x(\theta) \frac{\partial L^C}{\partial x(\theta)} = 0;$$

$$\frac{\partial L^C}{\partial \lambda(\theta)} = E_\omega \left\{ g_s(\theta) \cdot g_y(\theta) \left[ \sum_{\xi} \eta(\xi) V_c(\xi) \right] - \eta(\theta) V_y(\theta) \right\} \leq 0; \quad \forall \theta \in \Theta$$

(13)

and

$$\frac{\partial L^C}{\partial \xi(\theta)} = E_\omega \left\{ g_s(\theta) \sum_{\xi} \eta(\xi) V_c(\xi) + \eta(\theta) V_y(\theta) \right\} - \mu = 0; \quad \forall \theta \in \Theta$$

(14)

where $\mu$ is the dual variable associated with (6). When $x(\theta) > 0$, (13) implies that the change in global benefits associated with transferring a monetary unit from consumption to investment for GHG reduction in country $\theta$ must just equal the marginal cost $E_\omega \{ \eta(\theta) V_y(\theta) \}$ in lost consumption.
Assuming for the moment that \( x(\theta) > 0 \), we can compare (10) obtained earlier for the noncooperative case with (13) above. We see that (10) implies a similar benefit-cost equality to that discussed above for (13). In the noncooperative case, however, country \( \theta \) equates the marginal loss in consumption benefits to the benefits for itself of transferring a monetary unit in that country from consumption to investment. By contrast, for Pareto efficiency, marginal consumption losses are equated to global benefits of increased investment in mitigating GHGs.

Comparing the noncooperative solution with the first-best solution, we have shown elsewhere\(^3\) that:

i. The noncooperative solution is Pareto inefficient in the sense that there are weighting vectors \( \{ \eta(\theta) \mid \theta \in \Theta \} \) such that the corresponding cooperative solutions \( X(\eta), Y(\eta) \) leave every country better off than under the noncooperative solution.

ii. The level of aggregate GHG emissions \( G(X^C, Y^C) \) achieved under any cooperative solution is efficient in the sense that it is the minimum aggregate emission level achievable from total mitigation investments \( \Sigma x^C(\theta) \).

This illustrates how cooperation is key to improving efficiency in GHG mitigation efforts. The first finding indicates that increased cooperation itself can lead to increased efficiency, with respect to both consumption and investment patterns. The second finding notes, in particular, that the most basic level of cooperation could involve simply increasing the efficiency of investments in mitigation activities by focusing on the best alternatives for GHG mitigation investments globally.
3. An Illustrative Framework for Simulating Alternative Forms of Cooperation

In this section, we develop a simulation model to illustrate the general economic framework presented in Section 2. Since we make a number of assumptions to model country groups, the results reported in this section are indicative only and should in no way be construed as modeling the actual behavior of nations. The purpose of this simulation is to examine the relative consequences of various constraints to (or requirements for) cooperation in financing mitigation of GHG emissions. Throughout this section we maintain the assumption that GHG mitigation investments are purchased at incremental cost. This assumption is relaxed in Section 4 when we evaluate the relative consequences of a global market through which all GHG mitigation investments are made at a single market-clearing price.

3.1 The Simulation Model

We assume the following specifications for the general GHG production function and the aggregate welfare function in equations (1) and (2) above:

\[ g(x(\theta), y(\theta); \theta) = \left[ \beta(\theta) + \frac{\delta(\theta)(\alpha(\theta) - \beta(\theta))}{\delta(\theta) + x(\theta)} \right] y(\theta) \]  \hspace{1cm} (15)

\[ G(X, Y) = \sum_{\theta \in \Theta} g(x(\theta), y(\theta); \theta) = \sum_{\theta \in \Theta} \left[ \beta(\theta) + \frac{\delta(\theta)(\alpha(\theta) - \beta(\theta))}{\delta(\theta) + x(\theta)} \right] y(\theta) \]  \hspace{1cm} (16)

and

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\[ V(G(X, Y), y(\theta) \omega; \theta) = t(\theta) \log y(\theta) - h(\omega)\gamma(\theta)G(X, Y) \] (17)

where \(\alpha(\theta), \beta(\theta), \delta(\theta), t(\theta)\) and \(\gamma(\theta)\) are positive real numbers for each \(\theta \in \Theta\).

In the GHG production function (15), \(\alpha(\theta)\) is the rate of GHG production per unit of economic production and reflects the current technology and structure of the economy. Note that if the level of GHG mitigation investments, \(x(\theta)\), is zero, then \(g(\theta) = \alpha(\theta)y(\theta)\). As investments, \(x(\theta)\), rise, the rate of GHG production per unit of economic production declines geometrically toward \(\beta(\theta)\), a “best practice” rate for the economy. \(\delta(\theta)\) determines the amount of investment required to move the economy halfway toward its “best practice frontier”, \(\beta(\theta)\).

The aggregate welfare function (17) assumes diminishing returns to consumption and a linear GHG damage function. \(h(\omega)\gamma(\theta)\) represents the avoided cost of damage to country \(\theta\) in state of the world \(\omega\) due to global GHG emissions, \(G(X, Y)\). We denote the expected value of \(h(\omega)\) by \(\bar{h}\) and the expected value of \(h(\omega)\gamma(\theta)\) by \(\bar{\gamma}(\theta)\). Specification of parameters for (15) and (17) completely specifies the system of preferences for consumption, \(y(\theta)\), and investment in GHG mitigation, \(x(\theta)\).

Equations (15)-(17) are consistent with the maintained assumptions for \(g(\cdot, \theta)\) and \(V(\cdot, \theta)\) stated under equations (1) and (2) in Section 2. Budget constraint (5) and balancing condition (6) are maintained throughout. Analytical results for various specifications of (15)-(17) were obtained and are available from the authors. These analytical results were used to validate the numerical simulations reported in this section.
3.2 Model Parameters

We implement this simulation framework for six country groups according to income. India and China, owing to their size, are treated as a separate group as are economies in transition (countries of the former Soviet Union and Central Europe).

--- place Figure 1 about here ---

Parameters $\alpha(\theta)$ and $\beta(\theta)$ of the industrial CO\textsubscript{2} production function (15) have been selected for each country group, $\theta \in \Theta$, from the emissions data displayed in Figure 1.\textsuperscript{5} $\alpha(\theta)$ was selected for each country group such that industrial CO\textsubscript{2} emissions under the non-cooperative benchmark outcome, $g(x, y; \theta)_{NC}$, matches actual 1989 industrial CO\textsubscript{2} emissions. The investment required to move a group of countries halfway toward their "best practice frontier", $\delta(\theta)$, has been selected to be 1% of GNP for each country group. Assumptions for $\alpha(\theta)$, $\beta(\theta)$, and $\delta(\theta)$ for each country group are presented in Table A1. Using these values in equation (15) implies the incremental cost curves for CO\textsubscript{2} reductions shown in Figure 2. We leave refinements, such as a more accurate specification of possible cost functions for investments in GHG reduction technologies and extension to a dynamic setting, for future research.

--- place Figure 2 about here ---

Parameters $t(\theta)$ and $\overline{y}(\theta)$ in equation (17) model relative preferences in each country group for consumption and for avoiding damage due to climate change by investing in GHG abatement. We have selected $t(\theta)$ and $\overline{y}(\theta)$ for each country group, $\theta \in \Theta$, to reflect a high priority on consumption over

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\normalsize
investment in GHG abatement, a priority that diminishes with rising income. Expectations on $h(\alpha)$ are assumed to be identical across country groups. Assumptions for $t(\theta)$ and $\bar{\gamma}(\theta)$ for each country group are shown in Table A1.

Our assumptions for $t(\theta)$ and $\bar{\gamma}(\theta)$ of the aggregate welfare function (17) and $\delta(\theta)$ of the industrial $\text{CO}_2$ production function (15) are entirely arbitrary. As such, results presented in this section serve only as illustrations of the relative distributional and efficiency implications of different burden-sharing principles and forms of international cooperation.

3.3 Conditions for Cooperation: Negotiated Reduction Targets

A primary focus of this research is on ways in which cooperation can be achieved to enhance the expected welfare of each country relative to acting unilaterally in a fully non-cooperative fashion. As we noted in the introduction, conditions for global cooperation that ensure equity are likely to be very important in order to achieve the benefits of a cooperative solution. Furthermore, in addition to being a "lubricant for cooperation", as noted in the introduction, there are also moral arguments in favor of equitable burden sharing.

Before evaluating the performance of institutional arrangements on cooperation (section 4), we examine the implications of different constraints on cooperative action in financing GHG mitigation. We use the simulation framework presented above to assess how country groups are affected when several types of equity-driven conditions are imposed on the basic solutions developed in section 2. The
development here is entirely in the spirit of asking what can be done to make all nations better off relative to the non-cooperative benchmark.\footnote{7}

With negotiated reduction targets, all countries would agree ex ante to impose on themselves an explicit constraint on GHG emissions of the form $g(x;\theta) \leq k(\theta)$, where $k(\theta)$ might, for example, be emissions in a given baseline year. Equi-proportional rules are common in international environmental agreements. Such rules provide powerful focal points for discussions as they signal that each signatory country is expected to “pull its own weight” in terms of, say, equal emission reductions as a percent of status quo levels. Certain equi-proportional rules have emerged from discussions leading to the Framework Convention on Climate Change. One such equi-proportional rule is: developed countries should strive to reduce emissions by 20% from a pre-defined growth path by the year 2000 while developing countries would strive to reach a 20% reduction by 2025. Various other emissions limits have been proposed for climate change mitigation (e.g. see Grabler and Nakicenovic \cite{4}). These might take the form of restricting each country to a particular level of GHG emission per capita, or per unit of GNP. In the former case, for example, this would amount to appending to the first-best or to the noncooperative solution constraints of the following form:

$$
\frac{g(x(\theta), y(\theta), \theta)}{N(\theta)} \leq \psi \left( \frac{I(\theta)}{N(\theta)} \right)
$$

(18)

where $\psi(\ast)$ is a nondecreasing function of per capita income $I(\theta)/N(\theta)$. We will consider the impact of such a constraint using the simulation framework below.
Because of the difficulty of measuring GHG outputs, this constraint might be imposed on inputs, or on outputs in particular sectors (e.g., electric power). Alternatively, countries might choose to impose taxes on GHG emitting consumption, with the proceeds of these taxes being directed towards investment in mitigating the effects of GHG. Taxes on consumption could take the form:

\[ x(\theta) \geq \tau(\theta) l(\theta), \quad \theta \in \Theta \]  

(19)

where the tax rate \( \tau(\theta) \) could be an increasing function of per capita income levels \( I(\theta)/N(\theta) \). If \( \tau(\theta) = 0 \) for some countries, then the effect would be to impose targeted taxes only on certain countries (those for which \( \tau(\theta) > 0 \)). Again, these constraints would reduce aggregate unconstrained welfare, assuming cooperation, but might be required to assure cooperation.

3.4 Solutions with No Transfer Payments

3.4.1 Benchmark Non-Cooperative Outcome

The non-cooperative solution developed in Section 2.2 provides the benchmark against which all other solutions will be compared. In the benchmark case, each country group allocates GNP to consumption and investments in GHG reduction to maximize expected welfare with no transfers of resources between countries. The non-cooperative outcome from the simulation framework is shown in Table A1. The allocation of GNP to consumption, \( y(\theta) \), and GHG reduction, \( x(\theta) \), for each country group is imputed by our model using assumptions for (15)-(17) stated above. In this benchmark non-cooperative case, only the high income (OECD) economies (along with some transition economies) invest in mitigation.
of industrial CO₂ emissions. ICₙ(θ) is the incremental cost of investments to reduce industrial CO₂ emissions as depicted in Figure 2, above. In this setting, it appears that low cost opportunities for GHG abatement exist in developing countries.

3.4.2 Negotiated Target of 30% Reductions from 1989 Emissions: Across-the-Board

We now impose a constraint on the benchmark case that models a pledge to reduce emissions equi-proportionally: every country group pledges to reduce emissions by 30% from 1989 baseline levels. Key implications are displayed in Figure 3, which shows the expected welfare of each country group under this pledge relative to the non-cooperative benchmark (detailed results are shown in Table A1). High-middle income developing countries and OECD countries would find adhering to such a commitment unpalatable - domestic investments they must make to meet this commitment are greater than the benefits of reduced GHG emission, and this would reduce their net welfare. Without the ability to claim credit for financing GHG reduction in other countries, the incremental cost of achieving 30% reductions rises to prohibitive levels in both country groups (see Figure 2). If our assumed cost curves even remotely reflect actual conditions, commitments made to meet such a target must be seen as non-credible.

3.4.3 Negotiated Target of 30% Reductions from 1989 Emissions: Equal Per Capita Emission Rights

Another equity principle that has been put forward in climate change discussions is the concept of equal emission rights per capita. Using the country groups of our simulation framework, a cap on CO₂ emissions of 7 tons per capita per year would achieve a 30% reduction from G(X,Y)₁₉₈₉. At this level, global allowances would be well above 1989 emissions, but many country groups would not use their entire
quota. The constraint would not be binding on poor countries, but would be tightly binding on OECD countries where 1989 emissions averaged about 12 tons/capita. The expected welfare of each country group relative to the non-cooperative benchmark is shown in Figure 3. To meet this constraint without the ability to trade in obligations or rights, OECD countries would need to increase GHG abatement spending substantially and pursue very expensive projects while relatively low cost opportunities remain in developing countries (see details in Table A1). According to our illustrative framework, a strict application of this principle would not be acceptable to industrialized countries, but there would be substantial gains to trade in emission rights.

-- place Figure 3 about here --

3.5 Solutions with Transfer Payments

Now, we examine the implications of cooperation between country groups in the form of resource transfers between country groups. In these cases, country groups maximize expected welfare by allocating resources to consumption, investments in domestic GHG reductions, and to investments in foreign GHG reductions. We assume at this stage of the analysis that international transfers, $s(6)$, are optimally allocated to achieve the highest "bang-for-buck". Moreover, we assume that: i) perfect information exists on all investment opportunities for GHG reduction; ii) transaction costs for identifying and financing GHG reduction investments are negligible; and iii) all opportunities are made available for financing at incremental cost.
3.5.1 Cooperative Reallocation of GHG investments (without strategic adjustment)

In this case, countries efficiently reallocate among themselves the total pool of funds committed by individual countries for GHG investments in the benchmark non-cooperative outcome, $X_0$. However, in anticipation of such reallocations, countries are assumed not to strategically adjust their consumption and investment decisions. The problem may be expressed in the form:

Minimize \[ G(X,Y) = \sum_{\theta \in \Theta} g(x(\theta), y(\theta); \theta) \tag{20} \]

such that

\[ \sum_{\theta \in \Theta} x(\theta) \leq \sum_{\theta \in \Theta} x^{NC}(\theta) \tag{21} \]

which at optimum equates the marginal product of GHG investment $g_s(\theta)$ across countries.

Results from our simulation framework are labeled “first step” in Figure 4. Expected utility for every country group from this “first step” cooperative outcome is higher than in the benchmark non-cooperative outcome -- all country groups would be better off than in a non-cooperative world. Roughly 40% of OECD investments that would have chased high cost domestic projects in a non-cooperative world would instead finance higher “bang-for-buck” projects in developing countries (see details in Table A1). This efficient reallocation of global GHG abatement investments, $X_0$, would serve to reduce global industrial $CO_2$ emissions, $G(X,Y)$, by roughly the same levels as the negotiated reduction targets without transfer payments modeled above. Global cooperation in this way presents an opportunity for all countries to emerge winners -- the developed countries through winning the cooperation of developing nations and
access to high-payoff projects in these countries, and the developing countries through additional resources received for investment.

3.5.2 Cooperative Reallocation of GHG Investments (with strategic adjustment)

The preceding cooperative solution assumes that countries will not strategically re-adjust their committed levels of domestic investment and consumption in anticipation of international transfers. This is likely to be difficult to avoid in practice. However, outcomes obtained when strategic re-adjustment is accounted for still dominate the non-cooperative solution.

We characterize cooperative reallocation with strategic adjustment in a “sophisticated response” scenario in our simulation framework. Here, all country groups are allowed to reallocate resources domestically to maximize expected welfare, given the vector of resource transfers determined in the “first step” cooperative solution and subject to the constraint that positive transfers from the global coalition can be used only for investments in GHG reduction. Under these conditions, investments that would have been made in GHG reduction in a non-cooperative world by all non-OECD country groups would be entirely displaced by international resource transfers. Conversely, OECD countries would find it in their interest to increase domestic abatement investments substantially. This increased OECD investment would reduce global CO₂ emissions further and, thereby, result in welfare gains for all countries as shown in Figure 4 “sophisticated response” (details in Table A1).

-- place Figure 4 about here --

3.5.3 Cooperative Reallocation to Maximize OECD Welfare (with strategic adjustment)
Assuming that OECD countries will emerge as the exclusive financiers of global GHG reductions, it is natural to ask what level of transfers might be expected if the OECD were to maximize its own expected welfare by investing in GHG reductions in all country groups. As before, we assume that transfers from the OECD could only be used for investments in GHG reduction. Under these assumptions, our simulation framework shows that the OECD would increase its total resources devoted to domestic GHG abatement and transfers, relative to the previous outcome. The resulting investments would serve to reduce global GHG emissions even further and, thereby, make all country groups better off (see Figure 4 "OECD’s best").

3.6 Summary

We have shown, both analytically and through a simulation framework, that cooperation in financing projects to reduce GHG emissions dominates non-cooperation. Compare the cooperative solutions in Figure 4 with the commitments in a non-cooperative world modeled in Figure 3. Each cooperative scenario would achieve roughly the level of global GHG reductions that the commitments of Figure 3 aim to achieve, but each cooperative scenario is feasible since every country group is better off than in a non-cooperative world.

The scenarios evaluated above do not, of course, exhaust the kinds of commitments that are possible and may be necessary to ensure cooperation. From a policy perspective, it is important to examine how well various institutional arrangements may perform in enhancing cooperation. For each proposed institutional arrangement, the key issues to be evaluated are: i) information imperfections and asymmetries.

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that imply transactions costs in identifying and financing GHG reduction investments; ii) transactions costs of monitoring and enforcing commitments; and iii) the incentive structure determined by how the global surplus is to be shared between financiers and suppliers of GHG reduction projects. We examine these issues next in the next section.
4. Institutional Mechanisms for Implementing Global Collaboration

The analysis and simulation results provided in the previous sections clearly demonstrated the benefits (at both country and global levels) of various cooperative arrangements in GHG mitigation investment. The principles of the Framework Convention on Climate Change are consistent with these results. Each signatory country to the Framework Convention will be obligated to meet certain target limits on GHG emissions, possibly with the financial assistance from the global community. In the foregoing discussion we assumed the existence of an institutional mechanism to effect the international resource transfers necessary to achieve the desired benefits of cooperation. In this section, we examine alternative institutional designs to implement these actions based on criteria developed below.\textsuperscript{10}

We focus at the outset on two polar extremes in the possible set of institutional mechanisms: (1) pure multilateral schemes such as the Global Environmental Fund (GEF); and (2) pure bilateral schemes such as the joint implementation programs currently being proposed by the US and some other countries that plan to finance GHG reduction investments in developing countries. Multilateral schemes are characterized by a central pool of funds contributed by the investing countries which is then disbursed to recipient countries based on specific criteria, such as the incremental costs of the projects funded. Donor countries are not able to identify themselves with individual projects, which places a heavy burden of project monitoring on the central agency. In bilateral schemes, on the other hand, the terms of financing can be agreed by the two sides, and the country putting up the financing can monitor the progress of the projects. In such a bilateral approach, countries making cross-border investments may obtain credit or offsets against their own obligations under the Framework Convention. The benefit accruing to the financing countries, which is the avoided cost differential between the cost of domestic and cross-border
investment, is very visible, which makes it politically tenable to put up the financing from public funds. These alternative schemes are illustrated in Figure 5 below. After assessing the advantages and disadvantages of these schemes at some length, we consider the potential for hybrid approaches which combine the better features of multilateral and bilateral schemes. We consider the following criteria in our assessment:

- Price per unit of GHG reduced and total cost to investing countries
- Incentives for project nomination and efficient implementation
- Monitoring and informational efficiency
- Transactions costs

--- place Figure 5 about here ---

4.1 Cost to Investing Countries

The discussion in the previous section has proceeded on the assumption that the global community would have complete control in making investments in GHG mitigation projects without regard to issues of national sovereignty. The reality, of course, is that each country would be responsible for meeting the reduction targets it has committed to in the Framework Convention, and countries seeking to make cross-border investments would have to do so with the acquiescence of the recipient country.
A key issue that arises in this context relates to the basis on which transfer payments are made to recipient countries for the “purchase” of GHG mitigation. In the past, most notably in the case of the Montreal Protocol implementation, the basis for payment has been the incremental cost borne by the country of implementing the project. This approach has been criticized for being administratively cumbersome and providing few incentives (if any) for project acceleration by the recipient countries (see Allen et al. [1], Munasinghe and King [6]). Recent anecdotal evidence especially pertaining to the slow pace at which funds have been disbursed for the mitigation of Ozone depleting substances seems to confirm this view.

The simulations in Section 3 assumed that all projects are financed at their incremental costs, which implies that no surplus accrues to the recipient countries from this financing. Assuming recipient countries agree, this gives the highest “bang-for-buck” for the investment. If recipient countries are firmly committed to a schedule of investments which is not conditional on the availability of external financing, such an approach may be somewhat realistic, taking account also of the monopsonistic nature of the centralized multilateral institution. On the other hand, if the pace and size of GHG mitigation investment in recipient countries is dependent upon the scale of external financing, which seems to be a plausible scenario especially in the case of larger countries such as India and China, we would argue that payments in excess of incremental costs would be required for effective and speedy implementation of GHG mitigation projects.

Such an outcome is likely in a bilateral scheme where investor countries may be thought of as “competing” for low-cost GHG mitigation projects especially in the developing world. The likely result of such competition is that investor countries would be willing to pay recipient countries somewhat more than...
incremental costs to secure offsets through their investment in low-cost projects. In an extreme case, a single global “market-clearing” price which equals the incremental cost of the last project undertaken will be paid by investor countries for their cross-border GHG mitigation investments. The basic idea underlying this discussion is illustrated in Figure 6.

-- place Figure 6 about here --

Note that the single market price is similar to the price that would result from a market in emission permits, either at the global level or, as presently exists, at the national level.

Using the simulation framework, we have estimated the costs that would be incurred in the two polar cases we have been examining in this section: i) all cross-border investments financed at incremental cost (all surplus accrues to the financing countries); and ii) all cross-border investments financed at a single “market clearing” price (all surplus to host countries). These estimates are presented in Table 1 for two scenarios with transfer payments.

-- place Table 1 about here --

These simulation results illustrate the implications of alternative institutional mechanisms. Financing projects under a single market clearing price would result in a lower level of international transfers purchasing fewer GHG reductions than if projects were financed at incremental cost. International transfers would be relatively less cost effective under a market scheme since a large share of the transfers would be “incentive payment” in excess of project costs. Both simulation scenarios in Table I show that more than half of the international transfers would be surplus or “incentive”.
4.2 Incentive Implications

As noted above, the payment mechanism associated with the institutional scheme has a direct impact on the incentives for participation and active cooperation by the recipient countries. Buying GHG reductions at their incremental costs may be least-cost from the standpoint of the investing countries. However, as pointed out for the analogous case of ozone layer protection in Munasinghe and King [7], such an arrangement provides no financial surplus to the recipient countries -- which is likely to have an adverse effect on their incentives to cooperate by nominating and implementing projects speedily. This may be a less significant factor if the recipient countries are obligated by the Framework Convention to undertake these projects anyway, with or without external financing. However, it is unlikely that the cooperation of many developing countries can be obtained without such financing, and the experience to date shows that this may need to be in excess of the costs that they incur -- to provide an additional incentive.

Surplus payments in excess of costs may be viewed as "lubricants for cooperation". Since these surplus payments are likely to be highest for the lowest-cost (highest "bang-for-buck") projects, they create strong incentives for recipient countries to locate and nominate these projects for financing. They also create incentives for accelerated implementation of high "bang-for-buck" projects, which is very desirable from the standpoint of the objectives of the Framework Convention.

Also as we have noted above, surplus payments are almost inevitable in bilateral schemes if investing countries compete globally for the cheapest projects. However, taking account of the relative strengths and weaknesses of the parties to these bilateral schemes, the considerable barriers to information
flow, and the obligations imposed on the parties to the Framework Convention, it is very unlikely that prices will increase all the way to levels associated with full competition for mitigation projects.

Surplus payments may be very desirable in multilateral schemes also, to overcome the incentive problems that were discussed above. One approach to enhance incentives would be to conduct what amounts to a global auction (see Allen et al. [1]) which is effected by announcing a fixed price (in $/ton) which the multilateral institution would pay for mitigation projects. The effect of such a price offer is to attract all projects that have unit costs of GHG mitigation that are below the offered price, which will be the best projects available globally. Over time, the bid price can be increased progressively to attract higher cost projects, up to the desired aggregate level of GHG mitigation.

Figure 7 illustrates the impact of payments (bilaterally or multilaterally) in excess of the cost of the projects.

-- place Figure 7 about here --

4.3 Monitoring and Informational Efficiency

In order for a scheme of cross-border investments to work, the following criteria must be met regardless of the institutional mechanism that is adopted for implementing the scheme of resource transfers:

1. The investing countries should be able to monitor the investments/measure emissions and whether or not the desired results have been achieved;
2. The investing countries should be able to impose (at least moral if not financial) sanctions on noncompliant countries.

A third desirable characteristic of efficient decentralized implementation is that the shadow price of GHG reduction in each country and sector be estimable so that a rough efficiency benchmark (viz., equalized incremental abatement costs) is evident to all participating countries. Using market mechanisms at the national level could enhance significantly the estimation of incremental abatement costs in each country. For example, in the electric power sector if an efficiently functioning emissions trading market were present, the market price for an emissions permit for GHGs would represent the cost of a unit reduction in GHGs in that sector. The challenge is to link sectors such as electric power, which are more easily monitored and controlled, with other sectors, such as agriculture and manufacturing, where the total GHG emissions and the cost of reducing them will be considerably more difficult to estimate on an ongoing basis. In these sectors, from both a national as well as a global perspective, it seems likely that a variety of country-specific instruments and projects will be required to achieve efficient GHG mitigation in the implementation of Country Plans.

From the standpoint of monitoring and enforcement pertaining to specific projects, there appears to be no obvious advantage to one or other of the two mechanisms we have been considering here. Where it is possible to leverage off existing trade/investment/aid links between two countries, monitoring in a bilateral scheme could be very effectively handled. A multilateral agency, on the other hand, would have the benefit of some scale economies especially in the use of specialized expertise.
From the standpoint of gathering and disseminating information across countries, on the other hand, a centralized multilateral agency is at a clear advantage. Thus, even with bilateral investment flows, such a multilateral agency established and funded by the investing countries could perform a very valuable role in promoting cooperative activity by each signatory country, including sharing of best practices, publishing information on potential investments and their costs, highlighting priority areas and providing technical assistance.

4.4 Transactions Costs

The transactions costs of project selection, implementation and monitoring are clearly an important consideration in institutional design for GHG mitigation investment. Because of issues of national sovereignty and physical separation between investing and host countries, it is clear at the outset that the magnitude of transactions costs associated with specific projects will depend on the stance taken by the host country institutions towards these projects. Thus, for example, much of the work associated with the project could occur at the local or project level if the host countries were to take an active interest in the project, which would depend in part on their stake in the project. It is clear also that the transactions costs associated with project identification, financing and monitoring are likely to be very much a function of the size and complexity of the project, and also the role and competence of its local partners. If the incentives for local participation can be correctly structured to be consistent with the overall objectives of the project, this would greatly reduce monitoring needs and associated costs.

The level of transactions costs would also depend upon existing institutions. Many industrialized countries have existing agencies for the purpose of channeling foreign aid on a bilateral basis, which could
also be used for the purpose of channeling these investments. On the other hand, there is a long tradition of channeling development aid through multilateral institutions such as the World Bank. Hence, from the standpoint of transactions costs, the success of a new scheme of financing GHG mitigation projects would depend upon the extent to which existing institutional resources can be utilized.

4.5 Hybrid Approaches

It is clear from the foregoing that multilateral and bilateral schemes have their relative advantages and disadvantages. We summarize these below in Table II according to the criteria that we used above.

-- place Table II about here --

Multilateral approaches are informationally more efficient, since all available information can be centrally aggregated and then disseminated as available. On the other hand, paying out only incremental costs, as is currently the practice of the GEF, greatly reduces the incentives for host countries to take a proactive role in nominating and implementing projects. In the longer term, the cost of this may be considerably higher than the immediate savings in disbursements to the host countries.

In Figure 8, we propose an alternative hybrid arrangement where a centralized multilateral institution (e.g. a Global Environmental Coordinator) would undertake information transfers, assisting in project identification and technical assistance, and possibly keeping a scorecard of environmental investments and setoffs by individual countries. Investments themselves can be undertaken bilaterally, or directed through multilateral funds such as the GEF, depending upon the preferences of the countries.
concerned. In the latter case, our analysis would suggest the use of an auction type surplus sharing mechanism rather than merely compensating incremental costs.

-- place Figure 8 about here --
5. Conclusions and Directions for Future Research

The key focus of this paper has been on the benefits of cooperation in an effort to mitigate global climate change. As our results have demonstrated, there appear to be several cooperative outcomes which are more efficient in terms of GHG reduction and welfare improving for all countries, relative to the business-as-usual non-cooperative outcome. It is important that the global community strive for these outcomes.

Capturing the fruits of cooperation is contingent upon the development of effective institutional arrangements to transfer resources between countries. Given the nature of the investments (not so much the technology itself but the overlay of issues related to the externalities associated with the investments, national sovereignty and spatial dispersion), it is very important to have as many actions as possible undertaken by the host countries themselves in a way that is consistent with the objectives of the investing countries. As we have noted, this can be accomplished by a more equitable sharing of benefits between host and investing countries. The global environmental fund as it's currently constituted pays out incremental costs to the host countries, thereby capturing the entire project surplus for the global community. As is evident from the recent track record of the GEF, this dampens incentives for project selection and their speedy implementation, while also increasing the transactions costs expended by the global community. We examine more decentralized and market-oriented approaches, both bilateral and multilateral, which through the allocation of part of the surplus to host countries, have the potential to resolve these problems and considerably speed up the implementation of global environmental projects.

Fruitful areas for further research on the institutional design question seem to be the following:
• The analysis of effective policy implementation approaches and incentives to promote efficient (win-win) conservation measures which conserve GHG-rich resources.

• A targeted analysis of the energy sector with both conservation and efficiency in mind, including coordinating energy and environmental concerns with resource options, regulatory policy, privatization initiatives and other economic instruments.

• Assessment of the performance of decentralized instruments such as tradable emission rights, monitoring, regulated competitive structures, and incentive regulation. The assessment should couple both theory and empirical assessment, including simulation, experimental assessments and field studies.

• Empirical and theoretical research on the efficiency properties of alternative global institutional designs which meet the prima facie requirements of equity laid out in this paper. On both the theoretical and empirical sides, this could begin with a more detailed study of the efficiency consequences of various imposed equity constraints as discussed in Sections 2 and 3.
References


### Annex

#### Table A1  Simulation framework details

<table>
<thead>
<tr>
<th></th>
<th>Low Income</th>
<th>India &amp; China</th>
<th>Low-Middle</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
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<td>1989 population (millions)</td>
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<td>330</td>
<td>411</td>
<td>800</td>
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<td>1,163</td>
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<td>1.27</td>
<td>4.52</td>
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<td>δ(θ) 1% of GNP</td>
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<td>10.12</td>
<td>8.99</td>
<td>148.04</td>
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<td>τ(θ) 300,000 - 10*GNP</td>
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<td>289,880</td>
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#### 3.4.1 Benchmark non-cooperative solution

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<th>Y(θ) NC (US$ billions)</th>
<th>X(θ) NC (US$ billions)</th>
<th>x(θ) NC / Y(θ) (%)</th>
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<td>1,661.995</td>
<td>1,889.116</td>
<td>1,954.517</td>
<td>1,983.294</td>
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<td></td>
<td>18,303.90</td>
<td>255.10 Xθ</td>
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<td>20,584.00</td>
<td>95.02</td>
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### 3.4.2 Across the board 30% cuts from 1989 CO₂ emissions (no transfers)

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<th>India&amp;China</th>
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<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
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<td>954.89</td>
<td>888.11</td>
<td>13,802.44</td>
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<td>$x(\theta) / l(\theta)$ (%)</td>
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<td>0.47%</td>
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<td>$g(\theta)$ (T millions)</td>
<td>256.90</td>
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<td>989.10</td>
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<td>$IC_c$ ($/T$)</td>
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<td>70% of $g(x,y)^{NC}$</td>
<td>256.90</td>
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<td>3,414.60</td>
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<td>$EU(\theta) - EU(\theta)^{NC}$ (%)</td>
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### 3.4.3 30% Reductions based on equal emission rights per capita (no transfers)

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<td>$IC_c$ ($/T$)</td>
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<td>70% of $G^{NC}: g(x,y) = 0.90$ (t/cap)</td>
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<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>288.00</td>
<td>673.00</td>
<td>883.00</td>
<td>1,012.00</td>
<td>899.00</td>
<td>14,418.40</td>
<td>18,173.40</td>
</tr>
<tr>
<td>( x(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>4.08</td>
<td>27.12</td>
<td>13.85</td>
<td>4.53</td>
<td>48.01</td>
<td>157.51</td>
<td>255.10</td>
</tr>
<tr>
<td>( s(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>4.08</td>
<td>27.12</td>
<td>13.85</td>
<td>4.53</td>
<td>43.98</td>
<td>-93.56</td>
<td>0.00 S</td>
</tr>
<tr>
<td>( g(\theta) ) (T millions) ( \times 10^6 )</td>
<td>202.49</td>
<td>766.37</td>
<td>819.72</td>
<td>1,053.81</td>
<td>1,666.51</td>
<td>10,916.44</td>
<td>15,425.34</td>
</tr>
<tr>
<td>( EU(\theta) )</td>
<td>1,667.153</td>
<td>1,894.274</td>
<td>1,959.675</td>
<td>1,990.453</td>
<td>1,962.509</td>
<td>1,441.194</td>
<td>1,441.194</td>
</tr>
<tr>
<td>( IC(\theta) ) (S/Y)</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
<td>59.97</td>
</tr>
<tr>
<td>( EU(\theta) ) - ( EU(\theta)^{NC} ) (%)</td>
<td>0.31%</td>
<td>0.27%</td>
<td>0.26%</td>
<td>0.26%</td>
<td>0.26%</td>
<td>0.36%</td>
<td></td>
</tr>
</tbody>
</table>

3.5.2 Sophisticated response to transfers (free up own resources for consumption, transfers only for GHG reduction)

<table>
<thead>
<tr>
<th></th>
<th>Low Income</th>
<th>India &amp; China</th>
<th>Low-Middle</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>288.00</td>
<td>673.00</td>
<td>883.00</td>
<td>1,012.00</td>
<td>899.00</td>
<td>14,418.40</td>
<td>18,216.91</td>
</tr>
<tr>
<td>( x(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>4.08</td>
<td>27.12</td>
<td>13.85</td>
<td>4.53</td>
<td>43.98</td>
<td>248.52</td>
<td>342.09</td>
</tr>
<tr>
<td>( s(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>4.08</td>
<td>27.12</td>
<td>13.85</td>
<td>4.53</td>
<td>43.98</td>
<td>-93.56</td>
<td>0.00 S</td>
</tr>
<tr>
<td>( g(\theta) ) (T millions) ( \times 10^6 )</td>
<td>202.47</td>
<td>766.36</td>
<td>819.74</td>
<td>1,053.79</td>
<td>1,746.61</td>
<td>9,686.09</td>
<td>14,275.07</td>
</tr>
<tr>
<td>( EU(\theta) )</td>
<td>1,668.304</td>
<td>1,895.424</td>
<td>1,960.826</td>
<td>1,991.603</td>
<td>1,964.966</td>
<td>1,441.391</td>
<td>1,441.391</td>
</tr>
<tr>
<td>( IC(\theta) ) (S/Y)</td>
<td>59.98</td>
<td>59.97</td>
<td>59.96</td>
<td>59.98</td>
<td>51.56</td>
<td>101.65</td>
<td></td>
</tr>
<tr>
<td>( EU(\theta) ) - ( EU(\theta)^{NC} ) (%)</td>
<td>0.38%</td>
<td>0.33%</td>
<td>0.32%</td>
<td>0.32%</td>
<td>0.39%</td>
<td>0.37%</td>
<td></td>
</tr>
</tbody>
</table>

3.5.3 How well can the OECD do?

<table>
<thead>
<tr>
<th></th>
<th>Low Income</th>
<th>India &amp; China</th>
<th>Low-Middle</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>288.00</td>
<td>673.00</td>
<td>883.00</td>
<td>1,012.00</td>
<td>899.00</td>
<td>14,418.40</td>
<td>18,173.40</td>
</tr>
<tr>
<td>( x(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>6.17</td>
<td>37.27</td>
<td>20.65</td>
<td>8.92</td>
<td>65.28</td>
<td>247.31</td>
<td>385.60</td>
</tr>
<tr>
<td>( s(\theta) ) (US$ billions) ( \times 10^6 )</td>
<td>6.17</td>
<td>37.27</td>
<td>20.65</td>
<td>8.92</td>
<td>65.28</td>
<td>-138.29</td>
<td>0.00 S</td>
</tr>
<tr>
<td>( g(\theta) ) (T millions) ( \times 10^6 )</td>
<td>175.70</td>
<td>636.11</td>
<td>732.49</td>
<td>997.44</td>
<td>1,452.05</td>
<td>9,668.86</td>
<td>13,662.65</td>
</tr>
<tr>
<td>( EU(\theta) )</td>
<td>1,668.916</td>
<td>1,896.037</td>
<td>1,961.438</td>
<td>1,992.215</td>
<td>1,965.579</td>
<td>1,441.546</td>
<td>1,441.546</td>
</tr>
<tr>
<td>( IC(\theta) ) (S/Y)</td>
<td>101.35</td>
<td>101.34</td>
<td>101.31</td>
<td>101.36</td>
<td>101.34</td>
<td>101.33</td>
<td></td>
</tr>
<tr>
<td>( EU(\theta) ) - ( EU(\theta)^{NC} ) (%)</td>
<td>0.42%</td>
<td>0.37%</td>
<td>0.35%</td>
<td>0.35%</td>
<td>0.42%</td>
<td>0.38%</td>
<td></td>
</tr>
</tbody>
</table>

continued...
### 4.1.1 “First step” cooperative solution (allocation of $X_0$ to minimize $G(X,Y)$ under market conditions)

<table>
<thead>
<tr>
<th></th>
<th>Low Income</th>
<th>India&amp;China</th>
<th>Low-Middle</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y(\theta)$ (US$ billions)</td>
<td>288.30</td>
<td>693.12</td>
<td>884.44</td>
<td>1,012.00</td>
<td>919.30</td>
<td>14,552.93</td>
<td>18,350.09</td>
</tr>
<tr>
<td>$x(\theta)$ (US$ billions)</td>
<td>0.94</td>
<td>12.10</td>
<td>3.61</td>
<td>0.00</td>
<td>22.68</td>
<td>169.57</td>
<td>208.91</td>
</tr>
<tr>
<td>$s(\theta)$ (US$ billions)</td>
<td>1.24</td>
<td>32.22</td>
<td>5.05</td>
<td>0.00</td>
<td>42.98</td>
<td>-81.50</td>
<td>0.00</td>
</tr>
<tr>
<td>$g(\cdot, \theta)$ (T millions)</td>
<td>298.36</td>
<td>1,252.90</td>
<td>1,132.72</td>
<td>1,163.00</td>
<td>2,492.80</td>
<td>10,722.90</td>
<td>17,062.68</td>
</tr>
<tr>
<td>$EU(\cdot, \theta)$</td>
<td>1,665.824</td>
<td>1,901.277</td>
<td>1,958.512</td>
<td>1,988.815</td>
<td>1,968.678</td>
<td>1,439.557</td>
<td></td>
</tr>
<tr>
<td>$IC_c$ ($/T$)</td>
<td>18.02</td>
<td>18.02</td>
<td>18.02</td>
<td>28.64</td>
<td>18.02</td>
<td>64.80</td>
<td></td>
</tr>
<tr>
<td>$EU(\cdot, \theta) - EU(\cdot, \theta)^{IC}$ (%)</td>
<td>0.23%</td>
<td>0.64%</td>
<td>0.20%</td>
<td>0.18%</td>
<td>0.58%</td>
<td>0.25%</td>
<td></td>
</tr>
</tbody>
</table>

### 4.1.2 How well can the OECD do (under market conditions)?

<table>
<thead>
<tr>
<th></th>
<th>Low Income</th>
<th>India&amp;China</th>
<th>Low-Middle</th>
<th>High-Middle</th>
<th>Transition</th>
<th>High Income</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y(\theta)$ (US$ billions)</td>
<td>288.74</td>
<td>702.88</td>
<td>866.17</td>
<td>1,012.00</td>
<td>932.20</td>
<td>14,440.02</td>
<td>18,262.01</td>
</tr>
<tr>
<td>$x(\theta)$ (US$ billions)</td>
<td>1.48</td>
<td>14.91</td>
<td>5.39</td>
<td>0.00</td>
<td>27.41</td>
<td>247.80</td>
<td>296.99</td>
</tr>
<tr>
<td>$s(\theta)$ (US$ billions)</td>
<td>2.22</td>
<td>44.80</td>
<td>8.55</td>
<td>0.00</td>
<td>60.61</td>
<td>-116.18</td>
<td>0.00</td>
</tr>
<tr>
<td>$g(\cdot, \theta)$ (T millions)</td>
<td>272.40</td>
<td>1,132.84</td>
<td>1,048.66</td>
<td>1,163.00</td>
<td>2,296.23</td>
<td>9,678.54</td>
<td>15,591.66</td>
</tr>
<tr>
<td>$EU(\cdot, \theta)$</td>
<td>1,667.749</td>
<td>1,906.849</td>
<td>1,960.552</td>
<td>1,990.286</td>
<td>1,974.203</td>
<td>1,439.845</td>
<td></td>
</tr>
<tr>
<td>$IC_c$ ($/T$)</td>
<td>23.48</td>
<td>23.48</td>
<td>23.48</td>
<td>28.64</td>
<td>23.48</td>
<td>101.43</td>
<td></td>
</tr>
<tr>
<td>$EU(\cdot, \theta) - EU(\cdot, \theta)^{IC}$ (%)</td>
<td>0.35%</td>
<td>0.94%</td>
<td>0.31%</td>
<td>0.25%</td>
<td>0.86%</td>
<td>0.27%</td>
<td></td>
</tr>
</tbody>
</table>

Sources: Population and GNP data and country groups: World Bank [11]; emissions data: WRI [11]. Simulation parameters $x(\theta)$, $y(\theta)$, and $\gamma(\theta)$ are entirely arbitrary. $\alpha(\theta)$ has been selected such that emissions in the non-cooperative benchmark scenario match actual 1989 emissions.

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Figure 1  Industrial CO$_2$ emissions per unit income (kg/$\text{gdp}$)

Figure 2  Industrial CO$_2$ reduction supply curves ($/\text{ton of reduced CO}_2$)
Figure 3  Relative expected utility resulting from different allocation rules for 30% overall CO₂ reductions with no transfer payments

Figure 4  Relative expected utility from scenarios with transfer payments

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Figure 5 Investment Flows under Multilateral and Bilateral Institutional Schemes

Figure 6 Paying for GHG Mitigation Investments
Figure 7 The Sharing of Surplus between Investor and Host Countries

Figure 8 Investment and Information Flows in a Hybrid Scheme
Table I  Illustrative costs to investing countries under alternative institutional mechanisms

<table>
<thead>
<tr>
<th>Scenario</th>
<th>International transfers ($ billions)</th>
<th>CO₂ reductions due to transfers (tons million)</th>
<th>Incremental cost/market clearing price ($/ton CO₂)</th>
<th>Surplus ($ billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;First-step&quot; cooperative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ Incremental Cost</td>
<td>93.6</td>
<td>6,353</td>
<td>60</td>
<td>288</td>
</tr>
<tr>
<td>@ Market Clearing</td>
<td>81.5</td>
<td>4,522</td>
<td>18</td>
<td>42</td>
</tr>
<tr>
<td>OECD’s Best</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ Incremental Cost</td>
<td>138.3</td>
<td>6,868</td>
<td>101</td>
<td>555</td>
</tr>
<tr>
<td>@ Market Clearing</td>
<td>116.2</td>
<td>4,949</td>
<td>23</td>
<td>67</td>
</tr>
</tbody>
</table>

Source: Illustrative framework results in Table A1.

Table II  Comparison of multilateral and bilateral schemes

<table>
<thead>
<tr>
<th></th>
<th>Multilateral - I</th>
<th>Multilateral - II</th>
<th>Bilateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfers</td>
<td>at incremental cost</td>
<td>at incremental cost plus</td>
<td>at incremental cost plus</td>
</tr>
<tr>
<td>Total transfers required to equalize incremental costs</td>
<td>lowest</td>
<td>higher</td>
<td>highest</td>
</tr>
<tr>
<td>Incentives for accelerated implementation</td>
<td>weak</td>
<td>strong</td>
<td>strong</td>
</tr>
<tr>
<td>Information sharing</td>
<td>efficient</td>
<td>efficient</td>
<td>less efficient</td>
</tr>
<tr>
<td>Monitoring</td>
<td>good</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Transaction costs</td>
<td>high</td>
<td>lower</td>
<td>lower</td>
</tr>
</tbody>
</table>

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List of symbols

\( \theta \) theta
\( \in \) element
\( \Theta \) THETA
\( \omega \) omega
\( \mathbb{R}^+ \) positive real numbers
\( \eta \) eta
\( \forall \) for all
\( \partial \) partial derivative
\( \zeta \) placeholder for \( \theta \)
\( \mu \) mu
\( \alpha \) alpha
\( \beta \) beta
\( \delta \) delta
\( \gamma(\theta) \)
\( \bar{h} \) h bar
\( \tilde{\gamma} \) gamma bar
\( \psi \) psi
\( \tau \) tau

\( X \) (vector)
\( Y \) (vector)
\( S \) (vector)
\( X_0 \) X sub zero (non-vector)
\( E \) expectation
\( \Sigma \) sum
\( ^c \) superscript C
\( ^{NC} \) superscript NC
\( CO_2 \) CEE OH sub two

other symbols:

\( x(\theta) ; y(\theta) ; g(\alpha;\theta) ; s(\theta) ; t(\theta) ; k(\theta) ; h(\omega) \)
\( G(X,Y); U(\ast;\theta) ; V(\ast;\theta) ; W(X,Y) ; F(\omega); k(\theta); N(\theta); L^C \)
\( W_\eta ; E_{\text{ext}}; g_x(\theta); g_y(\theta); V_\alpha(\zeta); V_x(\theta); IC_x(\theta) \)
Footnotes

1 Constructive comments from Stephen Coate, Miguel Gouveia and Howard Kunreuther are gratefully acknowledged. We also benefitted from feedback at the IIASA Workshop on Risk and Fairness (June 19-22, 1993), the University of Michigan Graduate School of Management Workshop, the University of Pennsylvania Public Policy and Management Workshop, the “Energy Environment Nexus--Indian Issues and Global Impact” Conference at the University of Pennsylvania (April 1994), and the International Conference on Energy, Environment and the Economy (Taipei, August 1994). This research has been supported by a grant from the World Bank.

2 Note that the traditional approach to defining the Pareto set is to set individual country reservation expected utility levels for all but one country and then maximize the remaining country's expected utility over feasible allocation vectors (X, Y) and compensation vectors S and T (if compensation is allowed). As these reservation utility levels are varied, the Pareto set is generated. The present approach, using the weighted welfare function (3), is more congenial to the analysis, but it is entirely equivalent, where the weight η(θ) corresponds to the dual variable associated with country η's reservation utility level in the traditional approach. The reader will also note that many of these cooperative solutions will be unacceptable from the standpoint of the stated objectives of global cooperation, i.e. to minimize GHG emissions, since they also reallocate resources for consumption. However, this general formulation is convenient for characterizing the subset of solutions that will meet all necessary criteria, and we will examine specific cases of interest later.

3 Because income can always be productively invested in reducing GHGs, with strict improvements in welfare resulting therefrom, it is clear that the budget constraint (5) will hold as an equality at optimum.

4 A noncooperative equilibrium exists by the usual arguments.

5 Fernando, et al. [5].

6 Countries are grouped by income according to the 1991 World Development Report, World Bank [10]. Emissions data are from World Resources 1992-1993, WRI [11]. For purposes of this simulation model, we
account only for industrial CO₂ emissions. WRI [11] also reports net CO₂ emissions from land use changes, CH₄, CFCs, and the IPCC index of combined radiative forcing potential from all of these sources.

7. The application of various equity concepts to global climate change are reviewed by: Barrett [2]; Grubb, et al. [3]; Rose [8]; and Young and Wolf [12].

8. Country groups that spend nothing on GHG mitigation in the benchmark scenario obtain more marginal value from consumption than from investment in GHG mitigation. This result is entirely an artifact of our assumptions within the illustrative simulation framework.

\[ IC_x(\theta) = \frac{\partial x(\theta)}{\partial g(\theta)} = \frac{-(\delta + x)^2}{\delta (\alpha - \beta) y}. \]

9. It should be noted that we are not exploring intra-country implementation issues here. Decentralization at the national level has been extensively analyzed and various schemes, most notably tradable permits and taxes, have been developed to achieve target reductions in GHGs in various sectors efficiently. These alternative approaches themselves have yet to be examined fully in an empirical setting, and it seems likely that no single scheme will be optimal for every country (see Wheeler [9]). Thus, decentralization at the national level should be understood in terms of both differing sectoral targets for GHG mitigation, but also differing effectiveness of alternative policy instruments in achieving these sectoral targets in different countries. Thus, the key issue is that each country commits itself to a well-intentioned effort to achieve fair targets for GHG reduction. How they achieve this will be country specific, although sharing of best practices and new technologies across countries should be facilitated (see below).