CLIMATE CHANGE AND THE KYOTO PROTOCOL

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1. Introduction

This paper interprets the Kyoto Protocol in terms of game theory. Calling upon both positive and normative economics, it analyzes the issues at stake in the current international negotiations on climate change.

The negotiations on climate change[2], that have been taking place since the late 1980's within the United Nations institutions, are obviously a worldwide process, judging by the length of the list of the participating countries.[3] But these negotiations, prior to the Kyoto meeting, had led only to a "framework convention", signed in 1992 in Rio de Janeiro, that was little more than a declaration of intent. The real issue then was: are the continuing negotiations eventually going to lead to a sustainable agreement bearing on effective actions that is also worldwide? Or will they lead to a breaking up of the countries into separate blocks, each acting to the best of its own interests?

The Kyoto Protocol, signed in December 1997, has been a major development in the post-Rio evolution of these negotiations. Its importance lies mainly in the fact that it requires some countries to take effective actions that would become binding on them once they ratify it.

The Protocol does not require all countries to take specific actions. As our summary presentation reports more in details below, commitments to quantified emission reduction or limitation are mentioned only for the so-called "Annex-1" parties[4]. The role of the other countries in the agreement, while not ignored, is much less precisely specified.

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[2] For a thorough account of the scientific evidence on the state of the problem, the reader is referred to the work of the Intergovernmental Panel on Climate Change (IPCC), and in particular to the contribution of its Working Group III (see under IPCC 1995 in our references below). ANY LATER REFERENCE ?

[3] 178 in Rio, 159 in Kyoto and 161 in Buenos Aires.

[4] "Annex-1" (to the Rio Convention text) countries are the OECD countries, the former Soviet Union countries, and the Eastern European economies in transition.

One natural question that arises is whether the Kyoto Protocol is to be considered as just an "Annex-I" Protocol; or is it to be seen, after further thought and beyond the appearances, as a worldwide Protocol? Below, we defend the second thesis in terms of game theory.

2. Main features of the Protocol

We briefly note the main features of the Protocol[5] that are important from the point of view of our analysis:

(i) The Protocol proposes dated emission quotas, expressed in percentages of 1990 emissions, for Annex-I countries, to be met around 2012.

(ii) It proposes the principles of (a) *emission trading* by countries (or by their entities) and of (b) *joint implementation* by Annex-I countries.

(iii) It proposes a clean development mechanism (CDM) as a way to involve non-Annex-1 countries (especially developing ones) in some particular form of joint implementation and emission trading.

(iv) It allows trade in emissions only among those countries which ratify the Protocol. It is also expected that trade in emissions will not be allowed with countries that may not fulfil their obligations under the Protocol.

We may also note some of the features that the Protocol does not have:

(i) The Protocol does not set targets in terms of the accumulated stock of greenhouse gases. Its object is not a trajectory of stock of greenhouse gases, but it is emission flows per year from some point of time onwards.

[5] In Kyoto, the text of the protocol was adopted unanimously by the delegates of the 159 countries that participated in the negotiations. Signing of the text by governments and ratification by parliaments are the following stages of the process. The US, under the Bush administration, subsequently refused to ratify the protocol.

(ii) No explicit emissions ceilings have been proposed for non-Annex-1 countries and such ceilings, if at all, have to be negotiated in future rounds.

(iii) While the parties to the Protocol are expected to enforce the commitments made by them within their own countries, no sanctions are specified if a ratifying country does not fulfill its obligations under the Protocol, except for the above provision on being excluded from emission trading. A compliance regime, including possible sanctions for non-compliance, is yet to be specified in the course of future negotiations.

3. Economics of the issues at stake

Consider the *n* countries of the world (indexed by $i = 1, \ldots, n$) each of which enjoys an aggregate consumption level x_i, equal to the aggregate value of its production activities y_i minus damages D_i which consist of lost production due to global pollution.[6] The production activities of country i are described most simply by an increasing and strictly concave production function $y_i = g_i(e_i)$, where e_i is the fossil fuel energy input. Assume that the units have been so defined that a unit of fossil fuel use generates a unit of emissions as a by product. The emissions of country i are thus equal to e_i. Accordingly, $g_i'(e_i)(= dg_i(e_i)/de_i)$ is the marginal product of fossil fuel energy or the marginal cost of abatement, depending on the context. Damages in each country depend on the total emissions of all countries, i.e., on $\sum_{i=1}^{n} e_i$. They are represented by an increasing damage cost function $D_i = d_i(\sum_{j=1}^{n} e_j)$, which for simplicity is taken to be linear.[7] Each country's net output is thus given by the expression

$$x_i = g_i(e_i) - d_i \sum_{j=1}^{n} e_j, \tag{1}$$

where $d_i > 0$ is the damage per unit of emissions or, equivalently, the benefit per unit of abatement of country i.

[6] Several studies give estimates of these damage costs (see e.g. Fankhauser (1995) and Nordhaus and Yang (1996)). According to some estimates, damages *as a percentage of GNP* from a hypothetical doubling of CO_2 concentration for developing countries are substantially larger than for developed countries. The main reasons for the high estimates for developing countries are health impacts and the high proportion of global wetlands found in these countries. **What about Stern report or other more recent studies?**

[7] Numerical estimates of damages in some regions of the world are given in Table 1 below.

3.1. *The world optimality*

Ignoring distributional issues, the optimal world consumption is equal to the maximum of $\sum_{i=1}^{n} x_i$ with respect to the n variables $e_1, \ldots, e_n$. Let $(e_1^*, \ldots, e_n^*)$ be the vector of emissions of the n countries that achieve such a *world optimum*. These are obtained as a solution to the first order conditions for a maximum, i.e.,

$$g_i'(e_i^*) = \sum_{j=1}^{n} d_j, i = 1, \ldots, n. \tag{2}$$

Thus, at the world optimum, the marginal abatement cost of each country must be equal to the sum of marginal damages of all countries. Notice that the *world efficient emissions* are independent of the actual or current emissions of the countries. They depend only on the total marginal damage of the world.[8]

Negotiations on climate change must aim, at least in principle, to achieve the world efficient emissions. This would of course require transfers among the countries so as to balance the costs and benefits of attaining the world efficient emissions. We argue below that the Kyoto Protocol can be seen as a step in this direction and that a sequence of such steps can indeed lead ultimately to the world efficient emissions and optimal consumption.

3.2. *Reference emissions*

How does a country decide how much to emit? Low emissions imply a low production according to the function g_i, whereas high emissions entail high damages according to the function D_i. Classical economics reasoning suggests that each country can achieve its domestic optimum by maximizing its consumption level x_i with respect to e_i as defined in (1), taking as given all variables e_j with $j \neq i$. If all countries adopt such behavior, a Nash

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[8] However, the production functions, g_i, may change over time. Consequently, the world efficient emission levels may also change even if damages remain unchanged.

equilibrium between countries would prevail. This is given by the vector of emissions $(\bar{e}_1, \ldots \bar{e}_n)$ such that[9]

$$g_i'(\bar{e}_i) = d_i, i = 1, \ldots, n. \tag{3}$$

We note two characteristics of this Nash equilibrium: (i) the equilibrium emissions $(\bar{e}_1, \ldots, \bar{e}_n)$ are clearly not equal to the world efficient emissions, as can be seen by comparing (2) and (3), and (ii) $\bar{e}_i > e_i^*$ for each i, since g_i is concave and $\sum_{j=1}^n d_j > d_i$ for each i. Thus, the world efficient emissions are lower than those prevailing at the non-cooperative Nash equilibrium.

However, there is little empirical evidence to support that the countries do indeed decide their emission levels in this rational manner. Fulfilment of conditions (3) that characterize the Nash equilibrium requires domestic policies that involve either an energy tax or appropriately priced pollution permits such that the energy price including the tax or the permit price is equal to the domestic marginal damage cost d_i. Such domestic policies are often called “no regrets policies”.

If the firms in a country have strong lobbying power, they may be able to influence their government to keep the energy prices low. Since profit maximization by firms implies equality between the marginal product and the price of energy, this will lead to emissions $\breve{e}_i$ which are higher than $\bar{e}_i$ and such that $g_i'(\breve{e}_i) < d_i$, thus preventing the nationally rational policy from being adopted. If the firms and the government in each country behave in this manner, a different equilibrium - also non-cooperative in nature -would result, called the "market solution" by Nordhaus and Yang (1996) or "business-as-usual" by others.

Another reason why a nationally rational policy may not come about is that firms in a country may simply not be profit maximizers, as is the case with large public sector enterprises in some non-market economies. In such cases, the domestic equilibria are neither of the

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[9] Uniqueness of this vector is ensured under our assumptions of concavity of the functions g_i and linearity of the functions D_i.

"business-as-usual" nor of the "nationally rational" type, and energy prices do not induce any well defined emission policy — except for a generally low concern for efficient use of energy.

In sum, at least three types of country behavior are possible. But whatever be a country's behavior if its firms maximize profits and markets are competitive, its marginal abatement cost must be equal to the (average) domestic fossil fuel price in real terms. Given the concavity of the production function g_i, it follows that the higher the domestic fossil fuel price, the higher the marginal cost of abatement. As seen from Table 1 below such a relationship indeed holds (except in case of China, where, as is known, firms do not necessarily maximize profits).[10] In particular, the energy prices in the US are systematically lower and so is the marginal abatement cost. Moreover, for the three market economies of the US, the EU, and Japan, the higher the energy prices, the higher the marginal abatement costs.[11] For the other countries, we cannot say much, not only because of lack of data but also because they are either non-market or less developed economies, or both.

The marginal abatement cost of the US is low compared to that of the EU or Japan, it is next only to that of China, and significantly below that of India. Since the marginal damage cost of the US, which is the largest economy in the world, cannot be lower than, say that of the EU , this suggests that the US emissions are determined by the "business-as-usual" policy rather than by optimization at the national level.[12] On the other hand, domestic oil prices are kept high in India by imposing import tariffs not out of concern for the environment but to avoid an adverse balance of payment. The last column of Table 1 presents an educated guess about the type of domestic equilibrium that is likely to be prevailing in each country/region.

[10] The marginal cost of abatement may seem exceptionally high in case of Japan, but this is because of its large dependence on natural gas, price of which is relatively high, and less on coal and oil.
[11] Coal in Japan is a noticeable exception; but its use there is considerably lower.
[12] This is clearly a case of government, and not market, failure.

Table 1 — **Retail prices (in US$ per unit) of industrial fossil fuels, marginal abatement cost and damage cost in selected countries or regions**

	Heavy fuel oil for industry* (per ton)	Steam coal for industry* (per ton)	Natural gas for industry* (per 10kcalGV)	Marginal abatement cost/ton, for first 100 M ton reduction**	Annual damage cost as % of GDP***	Type of domestic equilibrium Conjectured
US	138.00	35.27	136.62	$ 12	1.3	$g_i'(\bar{e}_i) = p_i < d_i$
EU	187.4	76.0	182.0	$ 40	1.4	$g_i'(\bar{e}_i) = p_i \geq d_i$
Japan	172.86	49.90	423.12	$ 350	1.4	$g_i'(\bar{e}_i) = p_i \geq d_i$
India	191.15	19.36	Na	$ 22	Na	?
FSU	Na	Na	Na	$ 22	0.7	?
China	150.60	30.12	Na	$ 3.5	4.7	?

*****Source: *Energy Prices and Taxes* 1996

******Source: Ellerman and Decaux (1998)

*******Source: Fankhauser (1995)

4. A world treaty in the making

Let $(\bar{e}_1,\ldots,\bar{e}_n)$ be some vector of *reference emissions*. They may be the Nash equilibrium or the business-as-usual emissions. Or worse, they may be the outcome of a generally low concern for the efficient use of energy. In either case, the reference emissions are higher than the world efficient emissions. Reducing the emissions from the reference levels to the world efficient levels requires each country i to reduce its emissions by $\bar{e}_i - e_i^*$, imposing costs and benefits that are unlikely to be equal across the countries: some may have high abatement cost, i.e., $g_i(\bar{e}_i) - g_i(e_i^*)$, and little benefit, i.e., $d_i \sum_{j=1}^n (\bar{e}_j - e_j^*)$, while others may have low abatement costs and high benefits. Since the emission reductions must be agreed upon voluntarily by all countries, we need a scheme of transfers so as to balance the costs and benefits of reducing emissions. Chander and Tulkens (1995, 1997) indeed propose such a scheme. In the present context, it is defined as

$$T_i = \{g_i(\bar{e}_i) - g_i(e_i^*)\} - \frac{d_i}{\sum_{j=1}^n d_j}\left\{\sum_{j=1}^n g_j(\bar{e}_j) - \sum_{j=1}^n g_j(e_j^*)\right\}, i = 1,\ldots,n, \tag{4}$$

where $T_i > 0$ means a receipt by country i, while $T_i < 0$ means a payment by i. The first expression within the braces on the right is equal to country i's total abatement cost, and the second expression within the braces is equal to world's total abatement cost. The scheme thus requires country i not to bear its own abatement cost $g_i(\bar{e}_i) - g_i(e_i^*)$, but to bear instead a damage-weighted proportion, $d_i / \sum_{j=1}^n d_j$, of world's total abatement cost.

Clearly, $\sum_{i=1}^n T_i = 0$, which ensures a balanced budget if an international agency were established to implement the scheme. Notice the role played by the reference emissions $(e_1,\ldots,e_n)$ in the calculation of the transfers $(T_1,\ldots,T_n)$. Chander and Tulkens (1995,1997) assume the reference emissions to be equal to the Nash equilibrium emissions and show that the scheme enjoys several game theoretic properties. In particular, besides leading to the world efficient emissions, it implies coalitional stability in the sense that not only each country is individually better off, but also each coalition of countries is better off compared to what they would get by adopting any alternative arrangement among themselves in terms of emissions and transfers.

But what if the reference emissions are not equal to the Nash equilibrium emissions? In particular, if these are equal to the business-as-usual emissions of the type discussed earlier. It turns out that the game theoretic properties of the scheme are robust with regard to the reference emissions. If $(e_1,\ldots,e_n)$ are equal to the business-as-usual emissions, then the corresponding transfers $(T_1,\ldots,T_n)$ have the same game theoretic properties as when they are equal to the Nash equilibrium emissions. This is seen intuitively as follows: (a) the business-as-usual emissions are generally higher than the Nash equilibrium emissions, and (b) given (a) the payoff that a coalition can achieve for itself is lower, since the emissions of members not in the coalition are higher.

The first row of Table 2 provides an example of a vector of reference emissions. These have been estimated by Ellerman and Decaux (1998) on the basis of MIT's EPPA multi-regional and multi-sector computable general equilibrium model of economic activity, energy use and carbon emissions. We use these estimated emission levels in our arguments below and for obvious reasons refer to them as the business-as-usual emissions.

4.1. *Competitive emission trading*

Unlike the scheme above, the Kyoto Protocol does not propose any transfers among the countries. It only proposes ceilings or caps on the emissions of some countries, and these caps are obviously not equal to the world efficient emissions. Yet, as argued below, the Kyoto Protocol can be interpreted as a scheme of transfers and a step towards reaching the world efficient emissions. To see this, let us redefine the above scheme of transfers in terms of emission quotas and trade. This requires us to first introduce the concept of a "competitive emission trading equilibrium".

A *competitive emissions trading equilibrium* with respect to emission quotas $(e_1^0,\ldots,e_n^0)$ is a vector of emissions $(\hat{e}_1,\ldots,\hat{e}_n)$ and a price $\hat{\gamma} > 0$ (expressed in units of the consumption good per unit of emissions) such that for each country $i = 1,\ldots,n$,

$$\hat{e}_i = \arg\max\ (g_i(e_i) + \hat{\gamma}(e_i^0 - e_i)), \text{ and} \tag{5}$$

$$\sum_{i=1}^{n} \hat{e}_i = \sum_{i=1}^{n} e_i^0. \tag{6}$$

The first order conditions for maximization imply $g_i'(\hat{e}_i) = \hat{\gamma}, i = 1, \ldots, n.$ This means that competitive trade in emissions enables the countries to relocate the production and emission activities so as to maximize their total output while keeping their total emissions restricted to $\sum_{i=1}^{n} e_i^0$, since by definition $\sum_{i=1}^{n} \hat{e}_i = \sum_{i=1}^{n} e_i^0$ and $g'(\hat{e}_i) = g'(\hat{e}_j)$ for all, $i, j = 1, \ldots, n.$

In a competitive emission trading equilibrium, the countries trade in their "pollution rights" which are equal to their emission quotas ($e_1^0, ..., e_n^0$), at a given market price $\hat{\gamma}$, and at that price, demand and supply of pollution rights are equal. The amount $\hat{\gamma}(e_i^0 - \hat{e}_i)$ represents the value of payment, in units of the consumption good, for the purchase of pollution rights at the world market price $\hat{\gamma}$ if $(e_i^0 - \hat{e}_i)$ is negative or receipt from the sale of pollution rights if $(e_i^0 - \hat{e}_i)$ is positive.

Now, define emission quotas $(e_1^0, \ldots, e_n^0)$ from the world efficient emissions $e_1^*, ..., e_n^*$ and the reference emissions $(\bar{e}_1, ..., \bar{e}_n)$ such that for each country i,

$$(e_i^0 - e_i^*)\sum_{j=1}^{n} d_j = \{g_i(\bar{e}_i) - g_i(e_i^*)\} - \frac{d_i}{\sum_{j=1}^{n} d_j}\left\{\sum_{j=1}^{n} g_j(\bar{e}_j) - \sum_{j=1}^{n} g_j(e_j^*)\right\}. \tag{7}$$

The left hand side of this expression is what country i pays (or receives) if it buys (sells) pollution rights in amount $(e_i^0 - e_i^*)$ at price $\gamma^* \equiv \sum_{j=1}^{n} d_j$. In view of (2), $\gamma^* = g_i'(e_i^*) = g_j'(e_j^*), i, j = 1, \ldots, n.$ Which means that $(e_1^*, \ldots, e_n^*)$ and γ^* are nothing but the competitive emission trading equilibrium relative to the pollution rights $(e_1^0, ..., e_n^0)$. And the right hand side is equal to the transfer T_i advocated above to achieve world efficiency and a stable agreement.

Note that while the world efficient emissions $(e_1^*,\dots,e_n^*)$, as defined in (2), are independent of the reference emissions $(\bar{e}_1,\dots,\bar{e}_n)$, the pollution rights $(e_n^0,\dots,e_n^0)$, as defined in (7), are not. In fact, since the world efficient emissions are independent of the reference emissions and thus fixed, there is a one-to-one correspondence between $(e_1^*,\dots,e_n^*)$ and $(\bar{e}_1,\dots,\bar{e}_n)$. This means that if the countries are agreeable to the reference emissions $(\bar{e}_1,\dots,\bar{e}_n)$, then they should also be agreeable to the assignment of pollution rights $(e_1^0,\dots,e_n^0)$ and competitive trade in emissions, since by definition these would not only lead to the world efficient emissions $(e_1^*,\dots,e_n^*)$, but also to transfers that make each country or coalition of countries better-off relative to the reference emissions and consumptions. This shifts the argument from an agreement on pollution rights to an agreement on reference emissions $(\bar{e}_1,\dots,\bar{e}_n)$. However, reaching an agreement on reference emissions might not be easy. This has reference to the following two problems:

First, the current Nash or business-as-usual reference emissions $(\bar{e}_1,\dots,\bar{e}_n)$ that determine the transfers $(T_1,\dots,T_n)$ or equivalently the pollution rights $(e_1^0,\dots,e_n^0)$ may be considered unfair, especially by those countries which are in the early stages of their economic development. They currently have comparatively low emissions, while the emissions of developed countries are high. In the future, when they would have developed, the currently developing countries will have higher emissions and they might argue that those should be used as reference emissions instead of the current ones. Thus, the scheme of transfers, while Paretian (everyone is better off) with respect to the current Nash or business-as-usual reference emissions might be considered unsatisfactory by the developing countries. For instance, as seen from the first row of Table 2, India’s estimated reference emissions are nearly one-fourth of those of the US and substantially less than one-third of China. Obviously, India is unlikely to accept such low reference emissions compared to those of China and the US.

Second, if the reductions in the emissions, i.e. $\bar{e}_i - e_i^*$, are very large (as proposed by some countries), they are politically not feasible, at least in the short run.

4.2. *The Kyoto Protocol*

The Kyoto Protocol can be seen to address both these issues. Since the emissions of developing countries in general and of India and China in particular have not been subjected to ceilings, their emissions will rise as a result of their ongoing economic development and those of the Annex-1 countries will fall as a result of abatements and remain fixed at the levels agreed upon at Kyoto until at least further negotiations take place. With time the emissions of developing countries will become comparable to those of Annex-1 countries – likely to be sooner in case of China than India – and these might be then subjected to ceilings. Furthermore, the Kyoto Protocol only requires relatively small reductions for the immediate future, leaving further reductions for later periods. In other words, the Kyoto Protocol is not inconsistent with the ultimate goal of reaching an agreement on appropriate reference emissions $(\bar{e}_1,...,\bar{e}_n)$ in some future round of negotiations. In fact, it can be viewed as a step towards it.

For reaching an agreement on reference emissions the countries may have to first agree on adopting some equity principle. The currently considered baselines of business-as-usual or historically grandfathered emissions are clearly problematic. Similarly, the uniform per capita emissions, being advocated by India and China, are also unacceptable: if emissions cannot be grandfathered then by the same logic population size cannot be grandfathered either. A scheme of differential standards of emissions per unit of GDP is more likely to be acceptable, but it does not resolve the problem completely. As all the economies grow and their emissions rise, the standards may have to be revised from time to time and made more stringent. (Discussion from "Limits…" to be added here)

Whatever be the equity principle for determining the pollution rights, it seems unlikely from the figures in the first and second rows of Table 2 that the minimal emission reductions or non-reductions implied by the Kyoto Protocol would be inconsistent with it. This seems to be especially true in case of India, which unlike China has rather low emissions. What this means in policy terms is that the developing countries should not oppose the Kyoto Protocol and leave the issue of pollution rights, on which they have repeatedly insisted, to future negotiations. Implementation of the Kyoto Protocol will not only reduce the emissions of Annex-1 countries and thus improve the global environment, but will also strengthen the position of the developing countries in future rounds of negotiations as their emissions will continue to rise as their economies grow and become comparable to those of Annex-1 countries.

5. Alternative forms of emission trading

If each Annex -I country were to meet its Kyoto commitment e_i^0 on its own, the world output will be equal to $\sum_{i=1}^n g_i(e_i^0)$, which by definition is less than $\sum_{i=1}^n g_i(\hat{e}_i)$, where $\hat{e}_i$'s are the competitive trading equilibrium emissions, as defined in (5) and (6). In fact, as can be easily seen, competitive emission trading allows the countries of the world to restrict the total world emissions to their aggregate Kyoto commitment $e^0 = \sum_{i=1}^n e_i^0$ at least cost. Competitive trade in emissions thus enables the countries to reduce the world emissions efficiently.

As seen above each country or coalition of countries gains from competitive trade in emissions. However, this does not imply that each country or coalition of countries would be willing to participate in competitive emission trading. For that to be true we must show further that no country or coalition of countries can gain even more by forming a separate bloc and trading emissions only among themselves. An argument based on the theory of market games indeed shows that no coalition of countries can be better off compared to the competitive emission trading equilibrium by forming a separate bloc.

Let $S \subset N$ be a bloc of countries whose members decide, given their aggregate emission quota $\sum_{i \in S} e_i^0$, to adopt some joint policy of their own such as trading only among themselves or engaging in some other bilateral/multilateral agreements. The maximum payoff of such a bloc of countries is then given by

$$w(S) = \max \sum_{i \in S} g_i(e_i) \text{ subject to } \sum_{i \in S} e_i = \sum_{i \in S} e_i^0. \qquad (8)$$

This is the maximum total gross output that the countries in bloc S can jointly achieve, given their aggregate emission quota.[13]

[13] We ignore the damages because they remain the same, since the aggregate emission quota is fixed.

Consider again $(\hat{e}_1,\ldots,\hat{e}_n),$ the competitive trading equilibrium emissions relative to $(e_i^0,\ldots,e_n^0).$ We show that the payoff of members of S under the competitive equilibrium is not lower than their payoff when they form a separate bloc (as defined in (8)). This would establish that no country or coalition of countries will have incentives to form a separate bloc and not participate in competitive emission trading. This is in fact straightforward. Indeed, we only need to show that $\sum_{i\in S} g_i(\hat{e}_i) \geq w(S).$ Using (5), this is equivalent to $\sum_{i\in S}(g_i(\hat{e}_i)+\hat{\gamma}(e_i^0-\hat{e}_i)) \geq \sum_{i\in S} g_i(\tilde{e}_i)$ where $(\tilde{e}_i)_{i\in S}$ is the solution to (8). Since $\sum_{i\in S}\tilde{e}_i = \sum_{i\in S} e_i^0,$ we must show that $\sum_{i\in S} g_i(\hat{e}_i)+\hat{\gamma}(\sum_{i\in S}\tilde{e}_i - \sum_{i\in S}\hat{e}_i) \geq \sum_{i\in S} g_i(\tilde{e}_i).$ This inequality is true since each g_i is concave and $\hat{\gamma} = g_i'(\hat{e}_i)$ in competitive emission trading equilibrium. Therefore, $g_i(\hat{e}_i)+\hat{\gamma}(\tilde{e}_i-\hat{e}_i) \geq g_i(\tilde{e}_i),$ irrespective of whether $(\tilde{e}_i-\hat{e}_i)$ is positive or negative.

This leads to the conclusion that no country or coalition of countries will have an incentive to form a separate bloc and not participate in competitive emission trading.

Thus, the outcome of competitive trade in emissions among the countries cannot be improved upon by the formation of coalitions of countries, such as separate trading blocs. We are thereby rediscovering — in fact, just applying — a general property of competitive equilibria known as their "core" property, which says that competitive equilibria belong to the core of an appropriately defined cooperative game[14].

5.1. *Free trade in emissions*

While the Kyoto Protocol allows trade in emissions among the Annex-1 countries, it leaves open the questions of extent and nature of such trading.[15] Economic and game theoretic considerations can be further called upon to resolve these issues.

[14] The present game is a pure market game where externalities play no role, since, once the emission quotas are fixed, the public good aspect of the problem disappears. One is left with only the private goods-type problem of allocating the emissions between the countries. Note, however, that this is a game for an economy with production, and not that of the usual pure exchange type.
[15] An attempt was made to address this at the Conference of Parties in Buenos Aires in November 1998.

As to the extent of trading, that is, the number of participants in the trade, the market equilibrium theory generally favors trade among the largest number of economic agents. This is also implied by the previous argument against the formation of separate trading blocs or any other form of “coalitions” that restrict trade. Indeed, it is not to the benefit of any country or group of countries to form a coalition and act independently of the other countries.

Thus, it is in world's overall economic interest that non-Annex- 1 countries, whose emissions are not subject to quotas, be nevertheless allowed to participate in the trading process. The clean development mechanism (CDM) contains provisions to that effect. A policy implication of our claim is that this mechanism be designed so as to make it as open as possible to the largest number of countries. The fact that no quotas were assigned to these countries is irrelevant if the full benefits of trade in emissions are to be realized. Similarly, it is irrelevant whether or not a country ratifies the Protocol or has not met its commitment under the Protocol. Excluding a country from trade in emissions on any pretext hurts *all*.

As to the nature of trading, the same body of theory advocates that the institutions governing the trades be designed so as to ensure that they be as *competitive* as possible — competitiveness meaning here that all participants behave as price takers. It is indeed only for markets with that property that efficiency, coalitional stability and worldwide maximal benefits are established.

Regulatory provisions that restrict competitiveness in the emissions trading process are thus to be avoided. Such as, for instance, provisions allowing for market power to be exerted by some traders so as to influence price formation to their advantage, as well as regulatory controls that would impede sufficient price flexibility; or still, as proposed by some, limiting the quantities that can be traded.

As is well known, the larger the number of participants, the more competitive the market is likely to be: our argument favoring a large extent of the market is thus also one that favors competition[16]. Large numbers are admittedly neither the only way nor a sufficient condition to ensure the competitive character of a market, but they are a powerful factor.

[16] Our argument on the role of markets to achieve coalitional stability is also reinforced by a central result in economic theory (Debreu and Scarf (1963); Edgeworth (1881)) according to which *only* competitive equilibria are coalitionally stable, if the number of traders is large.

Table 2 below gives a numerical illustration of the outcome of competitive trade in emissions.[17] The competitive equilibrium price of emissions $\hat{\gamma}$ is estimated to be equal to \$24.75 per ton in 1985 dollars. Country i is an *exporter* of emission reductions if $e_i^0 > \hat{e}_i$ and an *importer* if $e_i^0 < \hat{e}_i$.. Country $i's$ gain from emissions trade is equal to $\hat{\gamma}(e_i^0 - \hat{e}_i) - (g_i(e_i^0) - g_i(\hat{e}_i))$ if it is an exporter and $g_i(\hat{e}_i) - g_i(e_i^0) - \hat{\gamma}(\hat{e}_i - e_i^0)$ if it is an importer – both are positive, since the price $\hat{\gamma}$ is equal to the *marginal* cost of abatement and g_i is concave. Exporting country i will not gain from trade if it is paid only its actual cost of abatement i.e. $g_i(\hat{e}_i) - g_i(\hat{e}_i')$ and all the gains from trade in that case will go to the importing countries. Competitive emission trading thus distributes the gains from trade among the exporters and importers in exactly the same way as it does in case of competitive trade in commodities.

Among the developing countries, China turns out to be the single largest exporter of emissions followed by India.[18] Among the Annex-1 countries, the US turns out to be the single largest importer followed by the EU. All countries gain from emission trading. The gains are substantial for both sides indicating the need for cooperation among the developed and developing countries for institutionalizing such trade.

Though, as the numerical example illustrates, all countries gain from trade in emissions, yet for several reasons there might be opposition to such trade from both developed and developing countries alike.

5.2. *The clean development mechanism*

Since restricting trade in emissions among the Annex-1 countries alone may affect both Annex-1 and non Annex-1 countries, this raises the question how to involve the non-Annex-1

[17] Additional details can be found in Ellerman and Decaux (1998), who also consider other trading regimes.

[18] There is however a practical difference between Annex-I trading and the modelling of global trading which tries to mimic a perfect CDM which may implicitly impose nominal quotas on non-Annex-I countries.

countries in emission trade without having them committed to any emission quotas?[19] This is difficult, but not impossible.[20] For example, one can calculate the impact of a tax increase on fossil fuel energy in a developing country and offer to transfer to the developing country an amount which is equal to the market value of the consequent reduction in its emissions.

However, the developing countries might fear that participation in any form of trade in emissions will amount to some sort of acceptance of emission quotas on their part. Developing countries like India and China have often expressed the view that the problem of climate change has been created by the industrialized countries and therefore it is these countries which should first reduce their emissions, no matter how, before the developing countries can consider accepting any quotas. The developing countries may not participate in emission trade also because the clean development mechanism is often interpreted as a form of trade that distributes the gains from trade entirely to the importing (read Annex-1) country and none to the exporting (read non Annex-1) country.[21] More specifically, it has been often proposed that rather than paying the exporting developing country i the market value at the competitive price, i.e. $\hat{\gamma}(e_i^0 - \hat{e}_i)$, the importing countries may pay only the actual cost of abatement, i.e. $g_i(e_i^0) - g_i(\hat{e}_i)$, which (given the strict concavity of the function $g_i(e_i)$) is strictly less than $\hat{\gamma}(e_i^0 - \hat{e}_i)$. This form of trade in emissions can be easily given effect by the importing countries by "offering" to cover the cost, and cost alone, of abatement activities in developing countries on a project- by- project basis.[22]

Both developed and developing countries might thus oppose the establishment of trade in emissions, though for entirely different reasons. In fact, the above mentioned positions or perceptions concerning trade in emissions seem to have been behind the deadlock at the negotiations held in Buenos Aires in 1999.

[19] One colleague has expressed this problem as follows: "… should we allow Mexico to "sell" permits to the US if it is not guaranteed that Mexico will really reduce emissions accordingly?"

[20] The recently proposed nuclear agreement between India and the US is a case in point, as it promises cleaner technologies to help India meet its energy needs. What would be the impact of this agreement on India's emissions and therefore how much emission reductions can the US claim to have imported?

[21] It is ironic that the same countries which generally extol the virtues of competitive markets should look for other forms of trading when it suits them.

[22] Though in theory this is not the only possible outcome and institutions can be set up to promote more competitive trading, there is a widespread concern among the developing countries that this will not be the case and a project-by-project approach is more likely to be adopted.

Given the above stated problems concerning trade in emissions between the developing and developed countries, the ultimate solution might be to first reach an agreement on the reference emissions that, as shown, can lead to well-defined pollution rights or entitlements for each country.[23] The Kyoto Protocol is not inconsistent with such a solution and in fact, as noted earlier, it is a step towards it.

Regardless of whether or not competitive trade in emissions is established, the developing countries stand to benefit from the implementation of the Kyoto Protocol. If the Annex-1 countries meet their Kyoto commitments, the international prices of fossil fuels will fall which would accelerate economic growth in developing countries.[24] The energy exporting non Annex -1 countries, however, might suffer economic losses because of (a) less revenue from energy exports and (b) higher prices of energy-intensive exports from Annex -1 regions. As shown by Babiker, Reilly and Jacoby (2000), other non Annex-1 countries such as India and China with a different mix of imports and exports might be better off.

In sum, future negotiations on climate change should aim at reaching an agreement on reference emissions. Such an agreement on reference emissions, as shown, will lead to an agreement on pollution rights and facilitate competitive trade in emissions. The Kyoto Protocol is not inconsistent with such an objective and, in fact, it can be viewed as a step towards it

[23] Besides facilitating competitive emissions trade among Annex-1 and non Annex-1 countries which would reduce the burden of Annex-1 countries of meeting their Kyoto commitments, assignment of such pollution rights or entitlements would create stronger incentives for the development and adoption of cleaner technologies even by the non-Annex-1 countries.

[24] In fact, the non-Annex-1 countries would benefit even more if, as some Annex-1 countries have suggested, no trade in emissions is to be established among Annex-1 countries and each country is to meet its Kyoto commitment on its own. This is so because then Annex-1 countries will not have access to the Russian "hot air" and the actual total reductions in emissions of Annex –1 countries will be much larger.

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Table 2 – Ellerman and Decaux characterization of the world competitive emissions trading equilibrium with respect to the Kyoto quotas

	USA	JPN	EEC	OOE	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW	World
Reference non-cooperative emissions in 2010 (Mton) $\overline{e}_i$	1838.25	424.24	1063.72	472.04	394.76	873.32*	927.39	1791.96	485.76	308.32	97.27	531.61	9208.63
Kyoto quotas of permitted emissions (Mton) e_i^0	1266.67	280.05	756.51	300.66	247.45	873.32	927.39	1791.96	485.76	308.32	97.27	531.61	7866.95
Post trading emissions reductions (Mton) $\overline{e}_i - \hat{e}_i$	186.22	12.33	74.96	60.07	52.98	213.36	52.54	447.93	104.87	42.78	2.50	91.07	1341.61
Emissions permits (Mton) imported (+) / exported (-) $\hat{e}_i - e_i^0$	385.36	131.86	232.25	111.31	94.33	-213.36	-52.54	-447.93	-104.87	-42.78	-2.50	-91.07	0.07
Marginal cost of abatement ($/ton) $\hat{\gamma} = g_i'(\hat{e}_i)$	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75	$ 24.75
Total cost of own abatement ($ billion) $g_i(\overline{e}_i) - g_i(\hat{e}_i)$	1.77	0.15	0.76	0.44	0.46	0.86	0.57	4.49	1.01	0.47	0.03	0.86	11.86
Cost (+) / receipt (-) of emission permits exports / imports ($ billion) $\hat{\gamma}(\hat{e}_i - \hat{e}_i^0)$	9.54	3.26	5.75	2.75	2.33	-5.28	-1.30	-11.09	-2.60	-1.06	-0.06	-2.25	0.00

Source: Ellerman and Decaux 1998, Table G (August version)

Annex-1 countries: USA, Japan (JPN), European Union 12 countries (EEC), other OECD countries (OOE), Eastern Economies in Transition (EET), Former Soviet Union (FSU).
Non-Annex -1 countries: Energy Exporting Countries (EEX), China (CHN), India (IND), Dynamic Asian Economies (DAE), Brazil (BRA), Rest of the World (ROW).
For non-Annex-1 countries, Kyoto quotas of permitted emissions, e_i^0, have been taken to be equal to their estimated non-cooperative emissions in 2010, i.e. $\overline{e}_i$, since it was agreed that their emissions need not be restricted in this round of negotiations.
*For FSU, we have taken the reference emissions, $\overline{e}_i$, to be equal to the Kyoto commitment (873.32), although the actual emissions have been estimated to be only (762.79). This is equivalent to giving credit for emission reductions that would happen in any case.