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The Kyoto *Protocol*, the Copenhagen *Accord*, the Cancun *Agreements*, and beyond: An economic and game theoretical exploration and interpretation

Parkash Chander and Henry Tulkens

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Center for Operations Research
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Voie du Roman Pays, 34
B-1348 Louvain-la-Neuve
Belgium
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Parkash CHANDER [1] and Henry TULKENS[2]

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Abstract

The paper is not intended for game theorists – unless they are interested in learning how their theories, and the theory of environmental games as developed in a forthcoming book, are being used for studying the current problem of climate change. Similarly for economists. In general, the presentation is addressed to those who have an interest in seeing how theory can shape policy in the area of climate change.

After a summary presentation of the relevant features of the Protocol, followed by the sketching out of an economic model serving as support for the theoretical construct, we consider a series of aspects of it – such as reference emissions, efficiency and stability, competitive trading, desirability of free trade in emissions and the clean development mechanism –, not to defend it and independently of the subsequent developments, but rather as a benchmark for understanding the various issues concerning the climate change problem in general. Then, we extend this exercise to an appraisal of the situation of the world climate regime that is currently prevailing, after the Protocol has entered into force. Finally, we discuss four aspects of the world climate regime that is likely to prevail after the expiry of the Kyoto commitment period 2008-2012.

Our message is a non-conventional one, compared with the common wisdom of commentaries of the Kyoto Protocol and of its follow-ups. It is inspired by research on the foundations of international cooperation in general and on climate change in particular.

Keywords: international environmental agreements, climate change, Kyoto Protocol, applied game theory, applied microeconomics.

JEL Classification: Q540, Q58, F020, D7, C7

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[1] National University of Singapore.

[2] Université catholique de Louvain, CORE, B-1348 Louvain-la-Neuve, Belgium.
E-mail: henry.tulkens@uclouvain.be

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The Kyoto *Protocol*, the Copenhagen *Accord*, the Cancun *Agreements* and beyond: An economic and game theoretical exploration and interpretation

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Outline

Introduction

As the title suggests, this paper interprets the situation created by the Kyoto Protocol and reflects on its likely successors in the light of the *theory of environmental games* introduced and fully developed in a forthcoming book[4]. Calling upon both positive and normative economics, it analyzes the issues at stake in the current international negotiations on climate change. The paper is meant mainly for practitioners and makers of policy on climate change. It is written in a style that is accessible even to those who may not want to master the theory. It is self-contained and references to the material in the book are intentionally kept at the minimum.

The negotiations on climate change[5], 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 countries which have taken part in the successive meetings[6]. 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[7]. The real issue then was: will the continuing negotiations eventually 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 independent separate blocks each acting – or not acting at all – 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.

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[4] *A Theory of Environmental Games*, by Parkash Chander and Henry Tulkens, Oxford University Press, forthcoming , 2012.

[5] For a thorough account of the scientific evidence on the state of the problem, the reader is referred to the assessment reports issued by the Intergovernmental Panel on Climate Change, referenced in the bibliography as IPCC 1990, 1995, 2001, 2007. The negotiations themselves take place in a body created by the General Assembly of the United Nations in 1992 under the name of United Nations Framework Convention on Climate Change (UNFCCC) and established in Geneva.

[6] According to the relevant UNFCCC websites of October 2009, 165 countries were present at the time of signing of the 1992 Convention in Rio, 84 were present at the December 1997 Conference of the Parties (COP) n°3 to sign the Kyoto Protocol, and 192 were present at the December 2009 COP n°15 held in Copenhagen.

[7] It should be mentioned that the "little more" mentioned above is far from being negligible as far as the future was concerned: for the implementation of any policy, an essential and preliminary component is that emissions be known. To that effect, the signatories to the Convention committed themselves to submit information regarding inventories of their emissions, annually for the countries listed in Annex 1, less frequently for the others. A UN administration has been set up, located in Geneva and Bonn, which is in charge of receiving, reviewing, compiling and publishing "national communications" containing these inventories (which did not exist before) as well as other reports on actions taken to reduce the emissions. It also organizes the successive COPs.

After a summary presentation in Section 1 of the main features of the Protocol that are relevant for our analysis, we sketch out in Section 2 the economic model that serves as the basic support for our theoretical construct. We then proceed in two stages.

First, taking the Protocol as it was signed, we consider in Section 3 a series of its characteristics, features and properties such as reference emissions, efficiency and stability, competitive trading, desirability of free trade in emissions and the clean development mechanism as a form of trading. Independently of the subsequent developments concerning the actual implementation of the Protocol, we use it as a benchmark for understanding the various issues concerning the climate change problem in general. Our theoretical reference had led us to offer at the time[8] an essentially constructive view of the Protocol. That view still inspires our renewed presentation here. It remains in contrast with more critical views offered by other commentators[9].

In Section 4, we extend this exercise to an appraisal of the situation of the world climate regime that has been actually prevailing during the first commitment period 2008-2012 in view of the subsequent non unanimous ratification of the Protocol. Since the Protocol does not require all countries to commit to achieve quantified reductions of their emissions, a list of the parties which agreed to reductions of their emissions appears as Annex B to the Protocol[10]. The role of the other countries in the agreement, although not ignored, is less precisely specified. Therefore, a central question is whether the Kyoto Protocol is to be considered as just an Annex B agreement, or is it to be seen, after further thought and beyond the appearances, as a worldwide agreement? In the two Sections 3 and 4 we defend and substantiate the second thesis.

Finally, in Section 5 we discuss the world climate regime that is likely to prevail after the expiry of the commitment period 2008-2012 and the nature of negotiations that may lead to it, given the Copenhagen 2009 Accord and its follow up.

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[8] In a paper written and circulated in 1998. It was eventually published as Chander, Tulkens, van Ypersele and Willems (2002).

[9] For instance, Nordhaus and Boyer (1999) have argued that "the strategy behind the Kyoto Protocol has no grounding in economics or environmental policy. The approach of freezing emissions at a given level for a group of countries is not related to a particular goal for concentrations, temperature, or damages. Nor does it bear any relation to an economically oriented strategy that would balance the costs and benefits of greenhouse-gas reductions."

[10] Annex B to the Kyoto Protocol is distinct from Annex I to the Rio Convention but both essentially list the OECD countries, the former Soviet Union countries, and the Eastern European economies in transition. The group is often referred to as "the developed countries".

1 Main features of the Protocol

Let us briefly note the main features of the Protocol[11] that are important from the point of view of our analysis:

(i) The Protocol proposes dated quotas of yearly emissions, expressed in percentages of 1990 emissions, for Annex B countries, to be met on average over the period 2008-2012.

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

(iii) It proposes a clean development mechanism (CDM) as a way to involve the non-Annex B 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 proposed that trade in emissions will not be allowed with countries that do not fulfill 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 averaged over the commitment period.

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

(iii) The parties to the Protocol are expected to enforce the commitments made by them within their own countries. But the text does not specify sanctions if a ratifying country does not fulfill its obligations under the Protocol, except for the above provision on being excluded from emission trading.

[11] In Kyoto, the text of the protocol was adopted unanimously by the delegates of the 84 countries that participated in the negotiations. Signing of the text by governments and ratification by parliaments was to take place later on. The Protocol was to enter into force only if 55 countries, representing 55% of the world total emissions ratified it. This occurred in February 2005, but ratifications by more countries continued and by October 2009, 189 countries had ratified the Protocol. In the meantime, the US, under the Bush administration, decided not to ratify, that is, not to submit the Protocol for ratification to the US Congress.

However, a compliance regime, including details of sanctions for non-compliance, has been set up in subsequent negotiations and eventually established by the Marrakech Accord of 2001, which is binding on all ratifying countries.

2 A basic model to deal with the economic issues at stake

Consider the *n* countries of the world (indexed by $i = 1,...,n$) 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[12]. 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[13]. 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[14]. 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*.

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 $(e_1^*,...,e_n^*)$ 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.*,

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

[12] Several studies give estimates of these damage costs (see e.g. Fankhauser (1995), Nordhaus and Yang (1996)), Stern (2006) and Tol (2009)). According to some estimates, damages for developing countries as a *percentage* of GDP from a hypothetical doubling of CO_2 concentration 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. The estimates, however, vary widely.

[13] Despite development of alternative sources of energy, more than 95% of world energy still comes from fossil fuels.

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

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 $\sum_{j=1}^{n} d_j$ of all countries[15].

In our interpretation, we assume that negotiations on climate change aim, at least in principle, at achieving world efficient emissions. Theory however teaches us that attaining this goal may be jeopardized, that is, an agreement on efficient emissions may be unstable, if for each country the costs and benefits are not properly balanced. However, the theory also shows that appropriately designed transfers between countries can remedy for that. We show in Section 3 that a system of tradable permits with initial allowances properly specified can play the same role as such transfers. We therefore argue in the sections to follow that the Kyoto Protocol, thanks to its "cap and trade" architecture and with appropriately selected reference emissions, can be seen as a step in the direction of an efficient and stable regime for the world climate, and that a sequence of such steps can indeed lead the countries of the world ultimately to an efficient and stable trajectory of emissions and consumptions.

3 A world treaty in the making

3.1 Reference emissions

How does a country decide how much to emit? Low emissions imply low production according to the function g_i, whereas high emissions entail high damages according to the function D_i. Following classical economics reasoning, we argue in Chapter 3 that each country can achieve its domestic optimum by maximizing with respect to e_i its consumption level x_i as defined in (1), taking as given all variables e_j with $j \neq i$. If all countries adopt such behavior, a Nash equilibrium between countries prevails, which in the framework of the above basic model consists of the vector of emissions such that[16]

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

[15] However, the production functions g_i may change over time because of changes in technology and/or in production capacity. Consequently, the world efficient emission levels may also change even if the marginal damages remain unchanged.
[16] Uniqueness of this vector is ensured under our assumptions of strict concavity of the functions g_i and linearity of the functions D_i.

We note two characteristics of this Nash equilibrium: *(i)* the equilibrium emissions $(\bar{e}_1,\dots,\bar{e}_n)$ are clearly not equal to the world efficient emissions $(e_1^*,\dots,e_n^*)$, 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.

Fulfillment 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 be equal to the domestic marginal damage cost d_i. Such domestic policies, which are nationally rational, are often called "no regrets policies".

However, there is little empirical evidence to support that the countries do indeed decide their emission levels in this rational manner. If the firms in a country have strong lobbying power, they may be able to influence their government to keep the energy prices low[17]. 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 - results, called the "market solution" by Nordhaus and Yang (1996) or "business-as-usual" by others.

Another reason why a nationally rational policy may not be followed 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 "nationally rational" nor of the "business-as-usual" 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 strict 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[18] such a relationship indeed holds (except in case of China, where,

[17] Not just firms: other economic agents may do the same. In some countries, governments subsidize fuels like kerosene used by the poor.

[18] This is an expanded version of Table 2.1 in Chapter 2 in that two more columns have been added.

as is known, state owned firms do not necessarily maximize profits)[19]. 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[20]. 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

Table 1 — Retail prices (in US$ per unit) of industrial fossil fuels, marginal abatement and damage costs in some 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)

"business-as-usual" policy rather than by optimization at the national level[21]. 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.

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[19] 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.

[20] Coal in Japan is a noticeable exception; but its use there is considerably lower.

[21] This is clearly a case of government, and not market, failure.

3.2 Efficiency and coalitional stability: the role of transfers

Let $(\overline{e}_1,\ldots,\overline{e}_n)$ 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 likely to be 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 $\overline{e}_i - e_i^*$. As this entails abatement cost, *i.e.*, $g_i(\overline{e}_i) - g_i(e_1^*)$, and benefits, *i.e.*, $d_i \sum_{j=1}^{n}(\overline{e}_j - e_j^*)$, the latter should exceed the former for each *i* to ensure that the emission reductions be agreed upon voluntarily by all countries. Now this is unlikely to be the case: some countries may have high abatement costs and low benefits, while others may have low abatement costs and high benefits. This is one of the rationales behind the scheme of transfers specified by the following[22] equation:

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

where $T_i > 0$ means a receipt by country i, while $T_i < 0$ means a payment by *i*. Its economic significance is as follows: the first expression within braces on the right is equal to country *i*'s total abatement cost, and the second expression within braces is equal to the world's total abatement cost – abatement costs which in either case are those entailed by the move from the reference emissions to the world efficient ones. The scheme thus requires country *i not* to bear its own abatement cost $g_i(\overline{e}_i) - g_i(e_1^*)$ but to bear instead a damage-weighted proportion, $d_i / \sum_{j=1}^{n} d_j$, of the 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.

Most importantly, the main virtue of the above scheme is that, if implemented together with the efficient emission levels $(e_1^*,\ldots,e_n^*)$, it guarantees that benefits after transfers exceed costs for all countries, be they considered individually or after forming coalitions of any kind[23]. Briefly stated, the solution so described enjoys the properties of *individual* and *coalitional rationality*. Not only each country is individually better off, but

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[22] This formula is adapted to the present context from the central equation (15) in Chapter 4 of the announced forthcoming book. It was originally introduced in Chander and Tulkens 1995 and 1997.

[23] The proof of this property, which is central to our theory, results from establishing that, for the cooperative game associated with the environmental economic model here under discussion, optimal world emissions together with the said transfers constitute a solution in the "core" of that game.

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.

Notice the role played by the reference emissions $(\overline{e}_1,\ldots,\overline{e}_n)$ in the calculation of the transfers $(T_1,\ldots,T_n)$. In our book, we only assume the reference emissions to be equal to the Nash equilibrium emissions and show that together with world efficient emissions the scheme enjoys individual and coalitional stability.

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 above? It turns out that the core-theoretic property of the scheme is robust with regard to the reference emissions. If $(\overline{e}_1,\ldots,\overline{e}_n)$ 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. Therefore the core is larger and includes more imputations.

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 such estimated emission levels at several stages of our arguments below and shall for obvious reasons refer to them as the business-as-usual emissions.

3.3 Competitive emissions trading in lieu of transfers

Unlike the scheme of transfers specified in (4), 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 probably not equal to the world efficient emissions. Yet, as we argue below, the caps on emissions of the Protocol, together with the trade that they induce, can be interpreted as a scheme of transfers and therefore its whole architecture as a step towards reaching emissions that would be both world efficient and coalitionally stable. To see this, we now redefine the above scheme of transfers in terms of emission quotas and trades. This requires us to first introduce the concept of a "competitive emissions 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 $i=1,\ldots,n$,

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

and

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

Assuming an interior solution, the first order conditions for maximization imply $g_i'(\hat{e}_i)=\hat{\gamma},\ i=1,\ldots,n$. This implies 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 $g_i'(\hat{e}_i)=g_j'(\hat{e}_j)$ for all, $i,j=1,\ldots,n$.

In a competitive emissions trading equilibrium, the countries trade in part or all of their "pollution rights" (which are equal to their emission quotas ($e_1^0,\ldots,e_n^0$)), at a given market price $\hat{\gamma}$, and at that price the demand and supply of pollution rights are equal. For each i 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.

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

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

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 emissions trading equilibrium relative to the pollution quotas $(e_1^0,\ldots,e_n^0)$. And the right hand side is equal to the transfer T_i advocated above as sufficient to induce coalitional stability of the world efficient emissions.

Note that while the world efficient emissions $(e_1^*,\ldots,e_n^*)$, as defined in (2), are independent of the reference emissions $(\overline{e}_1,\ldots,\overline{e}_n)$, the pollution quotas $(e_n^0,\ldots,e_n^0)$, 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 $(\overline{e}_1,\dots,\overline{e}_n)$. This means that if the countries are agreeable to the reference emissions $(\overline{e}_1,\dots,\overline{e}_n)$, then they should also be agreeable to the assignment of pollution quotas $(e_1^0,\dots,e_n^0)$ 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 quotas to an agreement on reference emissions $(\overline{e}_1,\dots,\overline{e}_n)$.

3.4 Agreeing on reference emissions

However, reaching an agreement on reference emissions might not be easy. For the following two reasons. First, the current Nash or business-as-usual reference emissions $(\overline{e}_1,\dots,\overline{e}_n)$ that determine the pollution quotas $(e_1^0,\dots,e_n^0)$ and the transfers $(T_1,\dots,T_n)$ 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 will 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, although 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[24]. Obviously, India is unlikely to accept such low reference emissions compared to those of China and the US[25].

Second, if the reductions to be achieved in the emissions, *i.e.* $\overline{e}_i - e_i^*$, are very large (as proposed by some countries), they are politically infeasible, at least in the short run.

The Kyoto Protocol can be seen to address both 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

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[24] Table 2 uses data from the MIT's EPPA model 1998. That model has not been updated, but China and India have grown faster than anticipated, especially China whose emissions now exceed those of US.

[25] The Prime Minister of India made a proposition at the G-8 summit held in November 2007 that the developing countries would never undertake anything that does not match the per capita emissions of developed countries.

development and those of the Annex B 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 B 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 to 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, typically in the second or a later commitment period.

For reaching an agreement on reference emissions the countries may have to first agree on adopting some equity principle. As discussed above, the currently considered baselines of business-as-usual or historically grandfathered[26] 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. Something that is time consistent and free of normative principles is needed[27].

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 initial allocation of pollution rights, on which they have repeatedly insisted, to future negotiations. In the meantime, implementation of the Kyoto Protocol will not only reduce the emissions of Annex B 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 B countries.

[26] Historically grandfathered emissions are business-as-usual emissions of some fixed year, not necessarily of the current year.

[27] The interested reader may want to refer back to the discussion of this issue in Chapter7.

3.5 Coalitional stability of the trading equilibrium

If each Annex B country meets its Kyoto commitment e_i^0 on its own, the world output is 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 emissions 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 emissions trading equilibrium by forming a separate bloc.

Let $S \subset N$ be a bloc of countries whose members decide, given their aggregate emissions 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 can obtain is then

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

given their aggregate emissions quota[28].

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 world-wide competitive emission trading.

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[28] We ignore the damages because they remain the same, since the aggregate emission quota $\sum_{i \in N} e_i^0$ is fixed.

To that effect, we 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 emissions trading equilibrium. Therefore, $g_i(\hat{e}_i)+\hat{\gamma}(\tilde{e}_i-\hat{e}_i) \geq g_i(\tilde{e}_i),\ i \in S$, 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 world-wide competitive emission trading.

Thus, the outcome of worldwide 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[29] .

3.6 Desirability of free trade in emissions

While the Kyoto Protocol allows trade in emissions among the Annex B countries, it leaves open the questions of extent and nature of such trading. Economic and game theoretic considerations can be further called upon to deal with these issues.

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.

[29] 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 game represents a production economy and not a standard pure exchange economy.

Thus, it is in the world's overall economic interest that non-Annex B countries, whose emissions are not subject to quotas, be nevertheless allowed to participate in the trading process. We shall argue below that the clean development mechanism (CDM) contains provisions to that effect. A policy implication 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[30].

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[31]. 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.

Table 2 below gives a numerical illustration of the outcome of world-wide competitive trade in emissions[32]. 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

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[30] One might even argue that it is similarly 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*. However, exclusion from trade is the only threat that can be exerted against a non complying country: the loss so incurred is thus to be seen as a cost to insure compliance. As to including CDM activities taking place in non ratifying countries, it may raise accounting issues in the host country. However, it has become only an academic question, since all countries, except the US, have ratified the Kyoto Protocol.

[31] 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.

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

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 at $\hat{e}_i$ 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.* $g_i(\hat{e}_i) - g_i(\hat{e}_i')$: all the gains from trade in that case would go to the importing countries. Competitive emissions trading thus distributes the gains from trade among the exporters and importers in exactly the same way as it does in the case of competitive trade in commodities.

Among the developing countries, China turns out to be the single largest exporter of emissions followed by India[33]. Among the Annex B countries, the US turns out to be the single largest importer followed by the EU. But all countries gain from emission trading as the numerical example illustrates, and the gains are substantial for both sides. This indicates the need for cooperation among the developed and developing countries by institutionalizing such trade.

Yet, for several reasons there might be opposition to such trade from both developed and developing countries alike.

3.7 The clean development mechanism as an alternative form of emissions trading

For the reasons mentioned in Section 3.6, restricting trade in emissions among Annex B countries alone may affect both Annex and non Annex B countries. This raises the question of how to involve the non Annex B countries in emissions trade without having them committed to any emission quotas[34]. That seems difficult, but it is not impossible[35].

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[33] There is however a practical difference between Annex B trading and the modeling of global trading which tries to mimic a perfect CDM, which may implicitly impose nominal quotas on non Annex B countries.

[33] 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?"

[34] 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?"

[35] 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 that is equal to the market value of the consequent reduction in its emissions. 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?

In fact, it is the main purpose of the clean development mechanism. In essence, trade occurs through "certified project activities"[36] located in non Annex B countries. The certification determines the amount of emissions reduction ("certified units") that the project generates, in comparison to a baseline that specifies what the emissions would be in the absence of the project. The amount of the reduction so achieved can then be sold by the initiator of the project to any economic agent belonging to an Annex B country, with the certified amounts being credited to meet the commitment of the country to which the purchasing party belongs.

The price at which the certified units are sold and purchased is determined by supply and demand for them, which are in turn determined by the supply of project activities and the demand of those Annex B countries for which buying such units is cheaper than reducing their own emissions. That competitive conditions prevail in the formation of this price is as necessary as in the formation of the price of the quotas in the emissions trading scheme of Section 3.6.

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.

In addition, the clean development mechanism is often interpreted by them as a form of trade that distributes the gains from trade entirely to the carbon credit importing (read Annex B) country and none to the carbon credit exporting (read non Annex B) country[37]. 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 given effect by the importing countries by systematically "offering" to cover the cost, and cost alone, of abatement activities in developing countries on a project - by - project basis. But the developing countries may accept this form of trading only if carbon credit importers collude so as

[36] As per the vocabulary of Article 12 of the Protocol.
[37] It is ironic that the countries which generally extol the virtues of competitive markets should look for other forms of trading when it suits them.

to behave monopolistically. Against this bias, there is the countervailing force of competition among the buyers, if there are many.

In the CDM construct, the determination of the baseline is of fundamental importance. As with emissions trading, the reference to it in the operation of the CDM points to the fact that the ultimate solution rests on the determination of reference emissions. We showed above how these can lead to well-defined emission quotas for each country, which in turn can induce efficient competitive trades in emissions. With the CDM being part of it, the efficiency properties of the institutional architecture of the Kyoto Protocol are thus much enhanced.

Finally, besides facilitating competitive emissions trade among Annex and non Annex B countries which would reduce the burden of Annex B countries of meeting their Kyoto commitments, the assignment of quotas to developing countries would create stronger incentives for development and adoption of cleaner technologies by them.

More generally, even regardless of whether or not the established trade in emissions is competitive, the developing countries stand to benefit from the implementation of the Kyoto Protocol. If the Annex B countries meet their Kyoto commitments, the international prices of fossil fuels will fall which would accelerate economic growth in developing countries[38]. The energy exporting non Annex B countries, however, might suffer economic losses because of (a) less revenue from energy exports and (b) higher prices of energy-intensive exports from Annex B countries. But other non Annex B countries such as India and China with a different mix of imports and exports might be better off, as shown by Babiker, Reilly and Jacoby (2000).

4 Appraising the first commitment period

We now wish to consider how the situation that has been prevailing during the commitment period 2008-2012 can be interpreted and appraised in the light of the book's theories. In the final Section 5, we shall also express some views that these theories inspire us to have on the situation that may prevail after the expiry date of 2012.

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

4.1 The post-ratification situation

By the end of 2009, the UNFCCC website listed, in its "Status of ratification" report of the Rio Convention, that 193 member countries of the United Nations, have signed and ratified the *Convention*[39]which had entered into force on March 21, 1994. With these 193 countries having thus taken part for more than 15 years in the implementation of the Rio Convention, our first claim earlier in this paper that the negotiations on climate change are a truly worldwide process is obviously verified.

But, as also mentioned at the beginning of the paper, the Convention has established only a *framework* for action in climate matters. Worldwide negotiations have taken place within this framework between the 193 countries, which have consisted in defining, comparing and evaluating a large variety of possible courses of action by the various countries. In other words, they have been exploring the players' strategy sets in the game.

After some time, the negotiations eventually led to the Kyoto Protocol, which was signed in 1997 and later by several governments, and subsequently (and more importantly) submitted for ratification to their countries' respective legislative bodies. The official date of entry into force of the Protocol is February 16, 2005, which is the date at which the required minimum number[40] of ratifications by countries was reached. Some additional countries ratified it during the subsequent months. By the end of 2009, 189 countries had ratified the Protocol, while one signatory-country – the US – has declared having no intention to do so[41].

4.2 A game theoretic interpretation

The text of the Protocol expresses a collective choice of specific actions to be taken by each one of the 190 countries which signed it. However, due to the non ratification by the US, the situation that prevails after all ratifications have taken place is different. Rather than the text of the Protocol, it is this factual situation that we consider as an outcome of the negotiations involving the 190 countries. By "an outcome" we mean what the countries decide to do, or formally commit themselves to do in terms of their emissions, after ratifications have taken place and from the moment of entry into force of the Protocol.

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[39] The non ratifying countries being at that date Andorra and the Holy See.

[40] Recall from footnote 9 that this is 55 countries, representing 55% of the world total emissions in 1990.

[41] Three countries, although having signed and ratified the Rio Convention, neither signed nor *a fortiori* ratified the Kyoto Protocol. These are Afghanistan, San Marino and Somalia.

This situation has a coalition structure akin to what we call in Chapter 4 (Section 4.2.3) a *Nash Equilibrium relative to a coalition* (NERC)[42], in which the coalition in question is the set of 189 ratifying countries whose joint strategy is what they have committed themselves to do according to the provisions of the Protocol. The strategy of the only non ratifying country – the US – is what emissions it decides to choose itself, which are likely to be higher than the emissions stated in the text it signed in Kyoto. In game theoretical terminology, we thus have prevailing, as the factual situation for the period 2005-2012, a "strategy profile" of the 190 players of the whole world, consisting of (a) jointly agreed upon strategies for the members of the coalition of 189, and (b) an individually decided strategy for one outsider.

What do the strategies in this profile precisely consist of? If we formulate them in terms of levels of emissions, there are three categories of them:

(a) For the 189 members of the coalition of ratifying countries:

- (i) For 37 countries listed in Annex B of the Protocol, the strategies are the levels of their emissions resulting from the assigned amounts of "quantified emissions reduction or limitation obligation with respect to 1990" mentioned in that Annex;
- (ii) For the other 152 "non Annex B" countries, the strategies are the levels of their emissions resulting from the "business as usual" evolution of their economies.

(b) For the non ratifying country, namely the US:

- The strategy is also the level of its emissions resulting from its "business as usual" evolution.

For the coalition of ratifying countries, the time span of their commitment is the period 2008-2012. The "outsider" country may join the coalition[43] at any time, if it so wishes.

The NERC thus appears to be a concept whose structure describes fairly well the situation prevailing during the commitment period 2005-2012. Strictly speaking, the situation itself might not be called an equilibrium because one cannot prove it to consist of best reply strategies in the technical sense; but one cannot claim the opposite

[42] This concept is identical to the one introduced in our earlier writings of 1995-1997 under the alternative terminology of "partial agreement Nash equilibrium with respect to a coalition".

[43] A few weeks after President Obama's election, one US official stated publicly in early 2009: "We are back in the game…". While pleasant to read, this statement makes little game theoretic sense: no player can leave a game with externalities when these are global since by definition they affect all players. In the climate change game, *all* countries of the world are necessarily in, irrespective of whether any one of them is in or out of a possibly existing agreement.

either. As a first approximation, let us consider it as a NERC nevertheless. What about its properties? Knowing that it is not Pareto efficient (like any NERC), a first observation is that the situation could be better for all, including the US. Less obvious is the property of stability, that we consider now in more detail.

Since the early 90s, the issue of stability of coalitions involved in international environmental agreements has been a matter of debate in the literature between two theses, respectively called "internal-external stability" and "core strategic stability"[44]. Let us examine the extent to which these two theories are pertinent for interpreting the world situation prevailing under the Protocol during the first commitment period.

We mention and discuss at length in Chapter 5 the central claim of the internal-external stability theory[45], which is to assert the intrinsic instability of large coalitions in international environmental affairs in general and in climate change ones in particular. This instability is attributed to the logical inevitability of free riding allowed by the public good characteristic of the externality involved. As a result, it is asserted that only small coalitions of countries can prevail and be expected to sign an agreement improving on the status quo.

Clearly, this view is not supported by the facts since a coalition of 189 countries has formed to ratify the Protocol, which is obviously not a small one. Within that large coalition, the free riding temptation seems not to be at work. Admittedly, there is not much room for free riding on the part of those in this group whose strategy is their BAU, but even among the group of 37 countries of Annex B we do not observe free riding in spite of the wide possibilities they have for it[46]. Thus, contrary to the assertion of the internal-external stability theory, an unquestionably large coalition is holding together for the period 2008-2012, after the entry into force of the Protocol.

The prevailing situation for that period is better explained in terms of the "γ-core theory" developed in our forthcoming book, which asserts Chapter 5 of that the grand coalition will form and adopt a world-efficient strategy if the players are farsighted and if the game of coalition formation is played repeatedly.

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[44] See Tulkens (1998) and Chander and Tulkens (2009) for reviews of this ongoing debate. A comparison between the two stability concepts is made in Bréchet, Gerard and Tulkens (2011) who use the CWS integrated assessment model for the computational part.

[45] Originally developed in Carraro and Siniscalco (1993) and Barrett (1994). An excellent non technical summary presentation can be found in Carraro (2008). A full development is contained in Barrettt (2003).

[46] After ratification, there may arise non compliance, as may well occur with Canada. But this is a different issue: the strategies we are interpreting are the ratification decisions, not lack of compliance with a duly ratified agreement.

Let us first note that the coalition that has formed is very close to the grand coalition since out of the190 players, there is only one missing in the ratified cooperative agreement now in force. We do recognize, however, that the missing player is an important one in terms of the weight of its emissions strategies in any resulting state of the world economy: because of that, the inefficiency of the prevailing NERC is surely considerable and we are thus far from what the grand coalition could achieve. We also have to recognize that this inefficient situation is to last for the whole first commitment period. Indeed, while 189 countries have formed a coalition and committed to not dissolve it before the expiry date of 2012, the US obviously has little incentive to ratify the Protocol since its benefits from free riding by not ratifying are far greater.

But, since the negotiations are still continuing and, as noted earlier (fn. 41), the US is reconsidering its position, the situation may be seen as an intermediate stage towards formation of the grand coalition. Indeed, the 189 countries are unlikely to continue with their emissions reductions beyond the expiry date of 2012 unless the US also agrees to reduce its emissions at the end of the current round of negotiations. If the US considers that threat to be credible, then as the γ-core theory predicts, it is likely to become a willing party to the agreement that may be reached at the end of the current negotiations on climate change, resulting in formation of the grand coalition. If not, then as the γ-core theory predicts, there may be no agreement at all and the world may return to the pre-Kyoto situation. In that case, the negotiation on climate change may continue beyond 2012 until an agreement which is ratified by all countries including the US is reached at some future date.

5 Post- Kyoto prospects: Copenhagen, Cancun and the road ahead

The above considerations result from an interpretation of facts and policies which is inspired by referring only to a static model such as the one of Section 2 above (and more fully developed in Chapters 3, 4 and 5 of the announced book). A dynamic model presented in Chapter 6 offers further insights, the main one of which is to suggest that there are good reasons – economic as well as game theoretic – to think of the Kyoto Protocol not as a one shot arrangement but instead as being embedded in a sequence of successive commitment periods to follow after the first one of 2008-2012[47]. The dynamic economic model and the associated dynamic games of Chapter 6 are the source of the considerations that follow. We group our arguments into four themes.

[47] Presently these are not officially defined, but 2012-2018 and 2019-2025 are mentioned in current preliminary discussions. The "good reasons" invoked for the long range view mentioned above are also by no means official.

(i) Time periods.

The essentially dynamic nature, in discrete time, of the climate change problem is brought to the forefront by the fact that the existing agreement is formulated in terms of a precise commitment period, implying that further ones may occur. Each one of these periods may be considered as being covered by a treaty of its own, but it would be very short-sighted not to think of them as part of a well structured sequence that constitutes an overall agreement extending possibly very far in the future. This is exactly what is captured by a solution concept for dynamic games that we propose in Chapter 6, namely a cooperative solution that consists of a sequence of emission and transfer strategies, which are immune to deviations by coalitions[48]. In that solution, a key role is played by "rational expectations games", played at each time period. This structure is inspired on the one hand by dynamic programming in discrete time, which allows for redefining strategies at each stage of the path, given what the state variables are at that stage and, on the other hand, by one shot games that come out of these redefined strategies and determine the course of the path for the next stage. These games are called rational expectations games because their payoff functions, which include the value functions of the dynamic programming model, embed an anticipation of "rational" future behaviors of the players.

During the first commitment period of that sequence (i.e. 2008-2012), we know from the interpretation developed in Section 4.2 above that the path actually followed by the countries of the world is not an efficient one, due to the US refusal to confirm by ratification its signing of the agreement in Kyoto. Only a partial agreement is in force. But the approach developed in Chapter 6 is flexible enough to deal with such unexpected deviations from the efficient path because it has the property that efficiency of the future path depends on the current state, not on how that state was reached.

(ii) The nature of strategies: cap and trade vs. command and control, national vs. sectoral, emissions abatement vs. temperature change.

As seen in Section 3.3, the cap and trade mechanism is the corner stone of the architecture of the Kyoto Protocol. It has been contested in many circles, the main alternatives being regrouped under the heading of "command and control". What can be said on these alternatives, in the light of the theory developed so far? The heart of the matter lies in the concept of "decision variables".

[48] Technically, we define in Chapter 6 the solution of the dynamic game involved as a sequence of "γ-core imputations" of games defined at each stage of the solution.

In the basic model of Section 2, the decision variables are the emission levels e_i whose effects on the environment were accounted for through a damage cost function[49] $D_i = d_i(\sum_{j=1}^{n} e_j)$. The cap and trade mechanism, as discussed in detail in Section 3.3 above, relies directly on the actual individual emission levels e_i as they result from trade, given the cap e_i^0 of each country *i*. Thus, the institutional structure specified by the Kyoto Protocol is closest to the reality at stake, as it bears on the relevant decision variables.

By contrast, what do "command and control" bear on? More precisely, what decisions do they consist of? In terms of the basic model, the answer to this question is that command and control essentially consist in modifying the production functions $y_i = g_i(e_i)$ in the sense of making it technically feasible to obtain reduced emissions e_i for various (possibly all) levels of output y_i . This means interfering with production processes throughout the economy, that may be formulated by denoting by $b_i > 0$ the quantity of resources devoted to technical progress (*e.g.* R and D expenditures) having the property just mentioned, and rewriting the production functions as $y_i = g_i(e_i, b_i)$ with $\partial g_i(e_i, b_i) / \partial b_i > 0$. Obviously emissions can be reduced in this way.

However, unlike emissions, the link between the decision variables b_i and the environmental target of temperature change (call it *z*) is only an indirect one and difficult to quantify. Therefore the actions of the parties involved are hard to specify and monitor. In addition, in the multi-agents setting that characterizes our problem, the environmental results eventually obtained in terms of *z* can hardly be traced back in a precise manner to actions taken on the variables b_i. As a consequence, cooperative agreements are much more difficult to formulate and implement in terms of the variables b_i.

It has also been proposed to define the various caps (or quotas) on emissions not by countries but rather by sectors of the world economy. At first sight this may be justified by the considerable differences by which the various sectors can react to emission reduction policies, as reflected by differences in their marginal abatement costs. But again, that ignores the fact that the key decision making units for restricting the emissions to the appropriate level are the nation states, which are in charge of negotiating and solving the problem of climate change. For this problem of international public good provision, sectors are to implement the states' decisions, not to make them.

[49] In a fuller treament of the subject (offered in our Chapters 2 and 3), the argument of this function is actually replaced by a so-called ecological transfer function $z = F(e_1, ..., e_n)$.

Finally, some recent negotiation "strategies", in the diplomatic sense of the word, have put forward a form of agreement that bears on the ambient environmental variable z, namely the amount of temperature change (or an upper bound on it), rather than on the level of emissions, *i.e.* the amounts of CO_2 emitted. In the vocabulary of dynamic optimization and dynamic games of Chapter 6, this amounts to make the agreement bear on the *state* of the system instead of on the *control* variables that determine it. Of course, the state of a system is not a control variable. Yet, the main element of the Copenhagen Accord is the recognition by the heads of nation states who signed it that an upper bound of +2°C is a necessity. Reference to emission reductions which could achieve that is left to an annex, containing promises to decide about them in near future.

It is unquestionable that the recognition by the US and China of the necessary +2°C ceiling is a major step towards the world's protection against climate change. However, decision wise, that is, in the technical sense of the expression of "decision variables" that we have been using since the beginning of this section, the accord is not a decision. Similarly, in game theoretic terms, it is not a joint strategy either. Therefore, the text of the Copenhagen Accord is by no means a solution of the game of climate change. However, the submissions by countries of voluntary emission reductions that the annex of the Accord invites are indeed strategies, or controls, in the technical sense. Whether these voluntary commitments are consistent with the goal of no more than +2°C temperature change is doubtful, but this is probably of less importance than the very fact that these commitments are being made, made publicly known, and thereby hopefully to be actually undertaken.

(iii) A fragmented vs. global world climate regime

Inspired by the results generated by the theory of internal-external stability of coalitions — which question the logical likelihood of a worldwide agreement on climate change — a stream of thought has spread the thesis[50], from the late 90's onwards, that only a "fragmented" structure of multiple regional agreements on climate change could ever emerge as an equilibrium outcome. As a corollary, this view directly objects to, or considers unlikely, the continuation after 2012 of the *global* cap and trade mechanism that was nevertheless established by the Kyoto Protocol.

In our developments in Chapter 5, we show the weaknesses of the theoretical underpinnings of the internal-external stability thesis. In our further discussion of it in Section 4.2 above, it was argued that it gives little ground for a convincing

[50] See for instance Carraro (2008), Buchner and Carraro (2009), Rubio and Ulph (2008).

interpretation of the Kyoto outcome for the period 2008-2010. Now, in the wake of the Copenhagen Accord of December 18, 2009 and its weaknesses, shouldn't one consider that a step has been taken in a direction which is different from that of the Kyoto Protocol, and in particular in the direction of local partial agreements for post-2012? We think not, for the following reasons.

Unlike the Kyoto Protocol, the Copenhagen Accord and the Cancun Agreements that followed in December 2010 do not establish a world climate institutional framework for any period of time. Rather, they announce that such a construction should be achieved in an institutional form ready for adoption at some following Conference of the Parties[51] to the UN Framework Convention on Climate Change. In the meantime, signatories of the Accord have communicated during 2010 which emission reductions they pledge to achieve and over which time period, and these have been officially recognized in the Cancun Agreements under the terms of "emission reduction targets". These pledges are not strategies in the game theoretic sense of the word: they rather are a work plan on how to get to the agreement that will contain the strategies to be effectively followed in the future. In other words, the pledges are only an expression of tactics towards achieving the global goal of restricting the rise in average temperature to +2°C in 2050, and not the content of a (new) treaty that could be considered as a solution of a game. Yet, the multilateral and mutual recognition of these pledges is a clear indication of a will of cooperation among the countries that have expressed them, and not a sign of fragmentation. Similarly the silence of the countries which have not expressed any pledge is to be interpreted as their choices of business as usual individual strategies, since there is no sign, among them, of countries seeking to establish separate groups of any kind.

Another indication that a drive towards full cooperation is prevailing after Copenhagen and Cancun is given by the fact that official documents preparatory to these meetings, especially those of two working groups established years ago for earlier COPs and still in place[52], reveal that most of the work has focused on whether and how to extend the scope of the Kyoto Protocol on various points, and not on proposing another mechanism which would be different from that of cap and trade[53] at

[51] Conference Of the Parties to the UNFCCC.

[52] The *Ad-hoc Working Group on Long-Term Cooperative Action under the UNFCCCC* (AWG-LCA) and the *Ad-hoc Working Group on Further Commitments for Annex I parties under the Kyoto Protocol* (AWG-KP). As their denomination indicates, the first of these two working groups emanates from the Rio Convention whereas the second emanates from the Kyoto Protocol. While active members of the former, the US are only observers in the latter, due to their non ratification of the Protocol.

[53] There was however a dissenting view on the global cap and trade mechanism expressed by the US, described in the Report of the AWG-LCA plenary meeting in Copenhagen 2009 (see *Earth Negotiations Bulletin* Vol 12, N° 459, pp. 18-19). To our knowledge it has not been repeated since then.

the world level. The Cancun Agreements explicitly urge these two ad-hoc working groups to pursue their work along the lines of what has been expressed thus far in their reports – in particular to ensure "that there is no gap between the first and the second commitment period[54].

Finally it is likely that a larger set of countries than those listed in Annex B of the Kyoto Protocol will announce future emission levels expressed in quantitative terms (that is, strategies in the standard game theoretic sense of the word). Although the nature of the strategies so communicated may in many cases still be of the BAU type, the essential point is that they are to be quantified *ex ante*, which was not the case under the Kyoto Protocol. This step is also to be considered as an increase in cooperative behavior since by doing so, these countries reduce the uncertainty regarding their future emissions, *vis à vis* the other players in the game.

These developments make us conclude that our interpretation of the current situation under the Kyoto Protocol, which was characterized above (p. 24) as an intermediate stage towards the formation of a world grand coalition, is not contradicted by the Copenhagen and Cancun events: they are consistent steps in that direction. An objection that may be raised against this view is that the emission reductions pledged by the countries are voluntary. How efficient can they be? Let us note first that it would be very hard to prove that the resulting aggregate is not efficient — more correctly, in economic dynamic terms, that the corresponding aggregate cap does not put the world on an efficient inter-temporal path. From the environmental point of view, as this aggregate cap will surely be less than what aggregate emissions would have been without Copenhagen and Cancun, this is at least progress towards a full cooperative agreement on climate change.

(iv) The participation of developing countries

As we have stressed before, full participation of all countries is necessary for reasons of overall efficiency. In addition to the reasons of general nature that explain why the emergence of a grand coalition raises difficulties in any game with diffuse externalities, the participation by developing countries in a worldwide international agreement is further problematic for two reasons, which are specific to the climate problem.

The first of these is summarized in the argument of "historical responsibility" of the countries that have polluted in the past, already mentioned above. Let us note first that

[54] Draft decision of COP16, as reported on the UNFCCC website

this notion is not without connection with the externality phenomenon, a connection already made in the review of environmental externalities that we present in Chapter 2. In addition to being a problem of stock externalities, climate change is also one of *intergenerational* externalities, because of the duration over centuries of the carbon that accumulates in the atmosphere. Emitters of today affect recipients of tomorrow, most of who are not even born. And victims of today are similarly affected by emissions made in the past by generations that no more exist. To that extent, direct negotiation between polluters and pollutees as we describe in Chapters 3 and 4 (let alone Coasean bargaining) cannot take place. Pollutees of today cannot charge anything to the polluters of the past[55], and symmetrically, polluters of today cannot buy from their future victims the right to emit today.

There is however an indirect way to make the polluters of the past "pay", namely, through their descendants. Indeed, as the emissions of the past have accompanied a glorious economic growth that some of today's populations are enjoying, it sounds as a natural application of the "polluters pay principle" that these populations take now a corresponding share in the responsibility for the current climate change.

The above argument is put forward when the determination of the time profile of abatement policies is under discussion. In particular, it takes the form of suggesting that developed countries "abate first", letting the developing ones join the effort only later, that is, when they will have reached a level of economic welfare comparable to the one of today's developed countries. This viewpoint was accepted at Kyoto in 1997, since according to the Protocol, no developing country is required to restrict its emissions at least up until 2012 while developed ones, that is, those listed in Annex B, are to have reduced globally theirs by the same deadline by an amount 5.2 % with respect to their 1990 levels. In diplomatic discussions on post Kyoto strategies in Copenhagen, this view was implicitly present in the insistence of some developing countries for a plain extension of the Kyoto Protocol after 2012.

In what form, to what extent, and at what speed is such participation to occur? In the spirit of our interpretation of the Protocol as presented in Section 4, participation of a country may have two meanings, which are complementary. One meaning is that the country just makes known in the treaty the quantitative emissions path that it considers as its BAU path for the commitment period under discussion, and to which the country commits itself in the sense that it serves as its reference emissions in the trading scheme. Let us call this the passive form of participation. As argued above, this

[55] They cannot expect any cleanup either (which is physically impossible): they can only adapt.

minimum form has the merit of essentially reducing uncertainty. A second, and stronger meaning of participation is to make known a quantitative emission path lower than the country's BAU path, to which the country commits itself for the commitment period under discussion, with this path serving as its reference emissions in the trading scheme. Let us call this the active form of participation.

Agreement on a new Annex B that lists the countries with their respective quantitative reference emissions just stated, reflecting their participation commitments, is then the answer to the question raised above as to the form and extent of participation of developing countries. As to the speed at which this evolving participation might occur, it is determined at each stage by the length of the next commitment period, a length that is part of the negotiations. But in fact, such a new Annex B would not be necessary because it would simply be identical to the list of all ratifying countries which by definition of ratification do announce an emissions path: BAU or lower.

Thus, the principle that "developed countries should abate first, letting the developing ones join the effort only later", takes the form of agreeing on gradually adjusted reference emissions in successive commitment periods which are all the more distant from the anticipated BAU emissions as the country is considered more "developed". This last point, i.e. development level, can be determined for instance on the basis of a comparison between the country's current GDP per capita and a "welfare threshold", to be negotiated. This is in the same spirit as the Jacoby rule[56] which proposes a formula linking the emissions reductions to a negotiated welfare threshold. However our proposal here bears instead on using such a threshold for determining *the reference emissions* on which the ensuing emissions trading is based, as originally mentioned in Chander (2003) and restated here in Section 3.4. In either case, the purpose is to implement over time switches of countries from passive to active participation in the sense described above, based on their evolving development levels. Comparable proposals are made in Frenkel (2009).

The actual country-wise emission abatements that will ensue will be determined by the permits market equilibrium (together with the reductions achieved under the CDM), and the geographical distribution of the actual emissions resulting from these trades may be quite different from the quotas assigned to each country in the treaty. But with the total of the quotas issued remaining equal to the total reference emissions

[56] Presented in Jacoby, Schmalensee and Sue Wing (1999)

agreed upon by the countries for the commitment period, as shown in Section 3.6, the global environmental objective of the period would be thereby achieved at minimal cost.

Finally, the second reason that makes problematic, in the mind of many, the participation of developing countries lies in the quandary created by the often asserted trade-off between emission limitations and growth of the economy. On this trade-off, also faced by developed countries, the game theoretical construct described above of gradual participation resulting from the solutions of a sequence of games played at successive commitment periods, does not bring anything additional. Growth considerations can of course be included in the specification of the BAU and other reference emissions to be agreed upon at the beginning of each commitment period.

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