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INTERNATIONAL ENVIRONMENT AGREEMENTS AND THE CASE OF GLOBAL WARMING

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INTERNATIONAL ENVIRONMENT AGREEMENTS AND THE CASE OF GLOBAL WARMING

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Summary:

First, this article uses standard welfare economics to illustrate the market failure and policy coordination problems caused by transboundary pollution problems in general and global warming in particular. Secondly, a brief overview is given of the main results obtained by empirical modelling exercises that combine both cost and damage estimates for global warming. Thirdly, the theoretical conclusions are confronted with the reality of ongoing international climate negotiations and the 1997 Kyoto Protocol is evaluated from an economic point of view. Finally, some recommendations are made for the design of future climate agreements.

Short contents:

Glossary of terms, abbreviations, symbols etc.:

GHGs: abbreviation for Greenhouse Gases. Six main GHGs are covered by the 1997 Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6).

IPCC: abbreviation for Intergovernmental Panel on Climate Change, http://www.ipcc.ch

UNFCCC: abbreviation for the United Nations Framework Convention on Climate Change that was signed in Rio de Janeiro during the Earth Summit in 1992, http://www.unfccc.int

Business-as-usual (BAU) or baseline scenario: description of what were to happen in the absence of deliberate policies to combat the environmental problem at stake.

Nash non-cooperative equilibrium: An allocation is called a Nash equilibrium if, assuming that all other countries stick to their respective Nash equilibrium strategies, no country can improve its position by playing another strategy than its very Nash equilibrium strategy. In the context of transboundary pollution problems this implies that countries neglect the negative environmental consequences of their consumption and production activities on other countries. The equilibrium concept is due to 1994 Nobel Prize winner John Nash.

Pareto efficiency: a situation is Pareto efficient if it is impossible to improve the welfare of one agent without deteriorating the welfare of other agents.

Cost efficiency: a burden sharing arrangement for the distribution of emission abatement efforts is cost efficient if it is impossible to decrease total costs by reallocating abatement efforts while maintaining the overall reduction target.

Integrated assessment models: models that combine a description of the economy with a stylised representation of the physical environment in order to achieve an explicit feedback between the economic and environmental variables.

Game theory: mathematical methodology in economic theory that analyses strategic interactions of agents starting from general behavioural assumptions. The aim of game theory is to make predictions on the possible outcomes of strategic interactions.

Annex B countries: list of signatories of the 1997 Kyoto Protocol that have assumed quantified emission ceilings to be attained by the first commitment period 2008-2012.

JI: abbreviation for Joint Implementation which is an instrument of the Kyoto Protocol enabling the exchange of emission reduction targets between two Annex B countries on the basis of a verifiable project.

CDM: abbreviation for Clean Development Mechanism which is also a project based instrument of the Kyoto Protocol for bilateral exchange of emission reductions. But in contrast to JI, CDM can be used by Annex B countries to buy emission reduction from non-Annex B signatories of the Kyoto Protocol.

Symbols used:

N	Set of countries in the world (cardinality of set *N* is *n*)
Ω	Time horizon (finite)
U_i	Life time utility of country *i*
Y_i^t	Production in country *i* in time period *t*
X_i^t	Consumption in country *i* in time period *t*
I_i^t	Investment in country *i* in time period *t*
K_i^t	Capital stock in country *i* in time period *t*
E_i^t	Emissions in country *i* in time period *t*
R_i^t	Emission reduction in country *i* in time period *t*
ΔT^t	Global mean temperature change in period *t*
$F_i^t\left(K_i^t\right)$	Production function for country *i* in period *t*
A_i^t	Shifting parameter capturing exogenous technological change in production technology for country *i* in period *t*
$C_i\left(R_i^t\right)$	Emission abatement cost function for country *i*
$D_i\left(\Delta T^t\right)$	Climate change damage cost for country *i*
$h^t\left(E_{N,}^1 E_N^2, \ldots, E_N^t\right)$	Temperature change function mapping global emission history into global mean temperature change at time *t*
δ	Rate of capital depreciation
ρ	Rate of time preference
σ_i^t	Emission-output coefficient for country *i* in period *t*

1. INTRODUCTION

In recent years the concern about the possibility of an enhanced greenhouse effect as a consequence of the emission of so-called greenhouse gases (GHGs) is rapidly growing. Under a business-as-usual (BAU) scenario without any specific policy to curb emissions of GHGs the Intergovernmental Panel on Climate Change Third Assessment Report expects that global mean temperature will rise by 1.4 to 5.8°C between 1990 and 2100. This would cause the sea level to rise by approximately 0.09 to 0.88 meter over the same period. Precipitation patterns would change drastically resulting in major shifts of agricultural production zones. Also the variability and likelihood of extreme events like hurricanes is projected to increase due to global warming. If one wants to reduce the negative consequences of this enhanced greenhouse effect, emissions of GHGs must be curbed significantly.

The greenhouse effect is a typical example of a global commons problem. Many fossil fuel users emit CO_2 that dissipates into the atmosphere and is mixed uniformly. The ensuing greenhouse effect affects all individuals in all countries of the world. It is well known that in this case individual abatement efforts in a non-cooperative laissez-faire equilibrium will not be optimal from a society point of view. In order to reach a socially optimal solution, international coordination of the GHG abatement efforts of the individual countries is needed.

Observation of reality immediately shows that the quest for cost efficiency (i.e. achieving an emission reduction target in the cheapest possible way) is not the only driving force in international negotiations on the coordination of greenhouse policies. Arguments related to the international income distribution are likely to play an important role. Leaders of developing countries emphasize that their economic situation justifies a lower abatement effort, the more so since the industrial world has been responsible for the large bulk of GHG emissions in the past. The problem is further complicated by the asymmetries related to costs and benefits of greenhouse policies. The negative effects of global warming are spread unevenly over the various parts of the globe and it is even possible that some regions might gain from a moderate temperature increase, at least in the beginning.

More important for the present discussions on emission abatement burden sharing are the huge international differences in the cost of abating emissions. An efficient worldwide abatement effort requires differentiation of abatement levels between countries. Moreover, in most cases such cost-efficient allocation will require greater efforts from the poorer countries since they are often characterised by relatively low abatement costs. In that case there is a direct conflict between equity and efficiency considerations. The relationship between efficiency and international distribution in the context of international environmental agreements will be an important focus of this paper.

In section 2 we introduce a stylised model of the climate-economy interactions. This model is a simplified version of the seminal RICE (Regional Integrated Climate Economy) model by William D. Nordhaus. In section 3 we first describe a reference laissez-faire scenario in which countries do not care much about climate change. This laissez-faire scenario is confronted with a normative burden sharing allocation derived from maximizing a global social welfare function. We discuss the different interpretations that can be given to the maximization of social welfare-approach. In section 4 we confront the theoretical model with reality for the case of global warming. First some general conclusions are drawn from empirical applications of integrated assessment models to global warming. Next, the main elements of the 1997 Kyoto Protocol are reviewed and are evaluated from an economic perspective. Section 5 concludes.

2. AN INTEGRATED ASSESSMENT MODEL FOR TRANSBOUNDARY STOCK POLLUTION PROBLEMS

We will use a highly stylised model to describe the economy-environment interaction. The problem of global climate change will serve as an illustration but the model is general enough to accommodate for other transboundary pollution problems. We tried to strip the model from all unnecessary details while focussing only on the most pertinent aspects of transboundary stock pollution problems. Stock pollution problems are caused by the accumulated stock of the pollutant in the environment, not by its emission flow as such. The model is a variant of a standard economic model to describe long-term economic growth in function of population growth and technological progress. The standard model is modified to allow for a global negative externality (for instance climate change or destruction of the ozone layer) that is positively correlated with economic production activities.

We denote by $N = \{1, 2, \ldots, n\}$ the set of all countries in the world. It is assumed that there is only one unique good that can be either consumed or used for investment in the productive capital stock. The unique consumption/investment good is produced using capital as main input A more general formulation would model explicitly other production inputs, in particular labour. We will assume that other inputs are supplied at fixed amounts and can therefore be subsumed in the functional form of the production function. Let Y_i^t denote production in period t for country i. The production technology is described by an increasing and concave production function:

(1) $$Y_i^t = F_i^t\left(K_i^t\right) = A_i^t f\left(K_i^t\right)$$

F_i^t, the production function for country *i* at period *t*, consists of a common function *f* and a shifting parameter A_i^t that captures exogenous technological progress. This shifting parameter is assumed to increase over time though it might do so at different rates in different countries. More sophisticated models allow for endogenous instead of exogenous technological change.

Capital accumulation is described by a standard dynamic relationship. Next period's capital stock consists of the non-depreciated part of today's capital stock plus current investment. Parameter $0 \le \delta \le 1$ stands for the capital depreciation rate, we assume the initial capital stock K_i^1 is given.

(2) $$K_i^{t+1} = \left[1-\delta\right]K_i^t + I_i^t$$

Production is assumed to cause emissions of greenhouse gases according to the following relationship:

(3) $$E_i^t = \sigma_i^t Y_i^t - R_i^t$$

where σ_i^t denotes the emission-output coefficient, i.e. the amount of pollutants emitted for every dollar of production. Emission-output coefficients can differ across countries and evolve over time. We will assume an exogenous decrease of this ratio corresponding to an autonomous improvement in energy efficiency. Emissions are in essence proportional to production but can be lowered by investing in specific emission reduction measures like replacing a coal fired power plant by renewable energy sources or investment in more fuel efficient cars. These emission abatement activities are captured by the policy variable $R_i^t \le \sigma_i^t Y_i^t$. However, emission reduction is costly and this is captured in the model by an increasing and convex emission abatement cost function. The convexity assumption refers to the idea that it becomes ever more expensive to reduce emissions by an extra unit for high levels of abatement.

(4) $C_i\left(R_i^t\right)$

Emissions of greenhouse gases accumulate in the atmosphere disturbing the global carbon cycle and causing ultimately climate change. We will capture the complex physical processes in the following general relationship:

(5) $\Delta T^t = h^t\left(E_N^1, E_N^2, \ldots, E_N^t\right), \qquad \Delta T^1$ given

Temperature change at time t depends upon the global GHGs emission history from period 1 to period t. Capital subscripts will be used to denote the sum of a variable over all individual countries. Hence: $E_N^t = \sum_{i\in N} E_i^t$. We assume that the function h^t is continuously differentiable and increasing in each of its arguments. Behind this simple and general specification is hidden the complex physical reality of the global carbon cycle and temperature change processes.

Temperature change gives rise to a variety of physical impacts like sea level rise, changes in precipitation patterns and extreme weather events and so on. The economic valuation of the damages caused by these impacts is summarized in a so-called climate change *damage function*:

(6) $D_i\left(\Delta T^t\right)$

The climate change damage function is assumed increasing and convex in temperature change reflecting the idea that additional damages will become more and more severe for high levels of temperature change, for instance due to non-linearities in the physics of the carbon cycle and temperature system.

Finally, we can state the resource balance constraint in the economy of country i:

(7) $Y_i^t - D_i\left(h^t\left(E_N^1, E_N^2, \ldots, E_N^t\right)\right) \geq X_i^t + I_i^t + C_i\left(R_i^t\right)$

The left hand side can be interpreted as "green" output, i.e. total output net of climate change damages. The right hand side stands for the different uses of this output, i.e. consumption, investment and investment in GHGs emission abatement. This resource balance constraint states that one cannot consume or invest more than overall green production in a particular country and period. This formulation implies that we do not consider trade flows between counties. This assumption is relaxed in many economic analyses but is not crucial for the results we will present in this article.

3. THE THEORY OF INTERNATIONAL ENVIRONMENTAL EXTERNALITIES

We will compare in this section equilibria or solutions for the economic model introduced above. In particular, we will start in section 3.1 with a non-cooperative or laissez-faire equilibrium that describes what were to happen if all countries only follow their self-interest. This section is positive or descriptive in nature. Starting from a behavioural assumption, it describes how rational agents will behave. Section 3.2 on the other hand is of a normative or prescriptive nature. It starts by postulating a general societal objective function and seeks an allocation of emission abatement efforts that maximizes this objective function within the constraints of economic possibilities.

3.1 Laissez faire equilibrium

Economic analyses of an environmental problem usually start by describing what were to happen in the absence of deliberate policies to combat the environmental problem. This is called the *baseline* or *business-as-usual scenario*. In order to define such a baseline scenario, one needs to make a behavioural assumption in order to predict what choices individual countries will make when they are confronted with an environmental problem. Almost all economic approaches assume that economic agents (consumers, producers, governments, countries) pursue their private self-interest. There is some controversy however on how to define self-interest in this respect, especially when dealing with long-term environmental problems like climate change.

For expository simplicity we will assume that individual countries maximize some inter-temporal utility function, in particular a simple discounted sum of future consumption levels:

(8) $$U_i\left(X_i^1, X_i^2, \ldots, X_i^{\Omega}\right) = \sum_{t=1}^{\Omega} \frac{X_i^t}{[1+\rho]^{t-1}}$$

This specific choice of objective function entails several implicit assumptions that need some commenting.

- We consider a finite (but very long, say several centuries) time horizon: $\Omega < +\infty$ and linear inter-temporal utility function involving exponential discounting. This means that the value in terms of period t consumption of an additional unit of consumption in period $t+1$ is always $\frac{1}{1+\rho} \leq 1$, independent of the consumption level. Countries are assumed to be "impatient", they value current consumption more than future consumption. Moreover, their degree of impatience is independent here of their consumption level. Further, it should be noted that there is a lively debate among economists on the exact value of the rate of time preference to be used in the context of climate change and on the appropriateness of exponential discounting in general.

- The formulation in (8) assumes that there exists some hypothetical representative agent that lives for the entire planning period from $t=1$ up to $t=\Omega$. In reality however, one should think of a sequence of several short-lived and possibly overlapping agents.
- The objective function (8) assumes away the internal political debate in every country. The choices made by a country depend on the outcome of a political process representing many different and diverse interests. It is well known in economic theory that aggregating those different preferences into one meta-preference might prove problematic.

In spite of its simplicity and restrictive assumptions, we will continue to use objective function (8) since it is common in a large part of the economic literature on climate change and since it allows us to illustrate in the most easy way the fundamental issues involved. The interested reader is referred to the bibliography for more realistic formulations of the problem.

In the absence of international cooperation on environmental policy, we assume that countries will simultaneously maximize the utility of their lifetime domestic consumption paths as given by (8) subject to their economy's resource balance condition (7) and capital accumulation process (2). For simplicity we will assume that strategies are chosen once and for all at the beginning of the planning period and are not to be changed afterwards.

In addition, temperature change and emissions are determined by the relationships in expressions (5) and (3) respectively. The control or policy variables in this dynamic optimisation problem are investment I_i^t and emission abatement effort R_i^t. Given a time path for these policy variables, the values of the state variables capital stock K_i^t and temperature change ΔT^t follow directly.

Solving this mathematical problem is beyond the scope of this article. We will limit ourselves to giving some flavour of the solution technique and to stating the basic insights. It should be noted here that one needs additional assumptions to resolve the interdependencies between the countries' optimal choices. Since the emissions of one country influence the level of climate change experienced by all other countries, every country needs to make an assumption on the emission behaviour of all other countries. This is usually done by invoking game theory and using some non-cooperative solution concept like the Nash equilibrium. An allocation is called a Nash equilibrium if, assuming that all other countries stick to their respective Nash equilibrium strategies, no country can improve its position by playing another strategy than its very Nash equilibrium strategy. Alternatively, in a Nash equilibrium every country chooses a strategy that maximises its individual pay off while assuming that the other countries continue to play their respective Nash equilibrium strategies.

The mathematical solution of the individual country's maximization problems gives rise to necessary conditions that characterize the optimal choice of the policy variables in terms of the underlying parameters of the model. Before reviewing the basics of these necessary conditions, we first define a new piece of notation $\kappa_i^t = \sum_{\tau=t}^{\Omega} \frac{D_i'\left(\Delta T^\tau\right)}{\left[1+\rho\right]^{\tau-t+1}} \frac{\partial h^\tau}{\partial E_i^t}$ that stands for the *individual shadow value to country* i *of all domestic future climate change damages due to emitting one additional unit at time* t. This shadow value consists of the discounted sum of all the future environmental damages weighted by the effect of a change of period t emissions on the entire future time path of temperature change ($\partial h^\tau / \partial E_i^t$). The shadow value is a measure for the valuation a country attaches to the expected future climate change damages as a result of a marginal increase in period t emissions. Note that this shadow value decreases in ρ. The more impatient countries are, the lower the valuation they attach to future climate change damages.

Laissez-faire optimal investment path

Using this new notation, the necessary condition driving an individually utility maximizing inter-temporal allocation of investment (and hence capital) boils down to:

(9) $$\frac{\partial F_i^t}{\partial K_i^t}\left[1-\sigma_i^t \kappa_i^t\right]-\delta=\rho \qquad \forall i, \forall t$$

The left hand side of this expression stands for the net return on capital. This return consists of the marginal product of capital minus the depreciation rate. But the return on capital is affected negatively by future climate change damages through the shadow value κ_i^t. The effect of future climate change damages is to depress the return on capital compared to a situation without climate change externality. Along an individually utility maximizing path, the capital stock should be such that net return on capital, corrected for future climate change damages, equals the rate of time preference.

Compared to a situation without climate change damages, condition (9) implies lower production growth rates. Indeed, if climate change would not cause negative externalities, i.e. if $\kappa_i^t = 0, \quad \forall t$, then the optimal investment path is characterized by the so-called "golden rule": $\frac{\partial F_i^t}{\partial K_i^t} = \delta + \rho \qquad \forall t$. This means that capital should be allocated over time in such a way that at every period, the marginal product of capital (i.e. the product of the last unit of capital invested in that period) equals the depreciation plus time preference rate. However, if climate change matters ($\kappa_i^t > 0$), marginal product of capital should be higher ($\frac{\partial F_i^t}{\partial K_i^t} = \frac{\delta + \rho}{1 - \sigma_i^t \kappa_i^t} > \delta + \rho$) implying a lower capital stock (because the productivity of each additional unit of capital is assumed to decline with higher levels of the capital stock, an assumption reflected by the concavity of the production function) and, as a consequence, growth rates.

Laissez-faire optimal emission abatement path

The necessary condition driving the optimal emission abatement effort can be stated as follows:

(10) $$C_i'\left(R_i^t\right) = \kappa_i^t \qquad \forall i, \forall t$$

The left hand side stands for the marginal cost in order to reduce emissions by an additional ton. In a non-cooperative or business-as-usual equilibrium, each country undertakes emission abatement up to the point where its own marginal cost of reducing emissions by one additional ton equals its own individual marginal benefit (i.e. the valuation of avoided climate change damages as reflected by the shadow value κ_i^t) of such an additional unit of abatement.

For the non-cooperative or laissez-faire equilibrium, the following conclusions can be drawn:

- It is in every country's self interest to undertake some emission abatement, even in the absence of international environmental agreements.
- The degree of domestic emission control in a non-cooperative equilibrium is a function of expected future marginal climate change damages within the country itself. Damages inflicted upon neighbouring states are not taken into account.

- The more impatient countries are (reflected by their rate of time preference or planning horizon), the lower their valuation of future climate change damages and the less emission abatement action they will undertake.
- It is optimal to restrict emissions through two channels. First, a country should lower overall production compared to a scenario without climate change by slowing down the rate of capital accumulation in the economy. Secondly, it should invest in emission control measures up to the point where marginal abatement costs equal expected future marginal damage costs.

3.2 Socially optimal level of environmental protection

It is intuitively clear that the non-cooperative laissez-faire equilibrium will not be optimal from the point of view of global society. This can be seen from the expression for the shadow value of future climate change damages. Every country reduces its emissions somewhat but it only takes into account domestic negative emission externalities while ignoring spill over effects to neighbouring countries. This lack of internalisation of external costs in the laissez-faire scenario is the main rationale for international coordination of environmental policies.

Knowing that the laissez-faire situation is not optimal, the next question arising is: what is the socially optimal amount of emission abatement for an international environmental externality problem like climate change? In this section, we will explore normative benchmark solutions to the international externality problem. The basic questions are the following:

1. What is the socially optimal level of global warming, or stated differently, how much global emission abatement is desirable from a social point of view? This is the question of "*how far should we go in avoiding climate change*"?
2. Given an answer to the previous question, how should this emission reduction effort be allocated over the different countries in the world? This is the *problem of burden sharing*.

Defining a socially optimal outcome is by definition a normative exercise that requires one to start with the specification of an objective to be pursued by society. Economists often use the concept of Pareto efficiency as a normative objective for society. A situation x is said to constitute a *Pareto improvement* over another situation y if everyone is at least as well off in situation x compared to situation y and at least one person is strictly better off. A situation is said to be *Pareto efficient* if it is impossible to find further Pareto improvements, i.e. , if it is impossible to improve the well-being of one person without deteriorating the position of other persons.

Pareto efficiency is an appealing normative concept for two reasons. First it entails the idea that resources should not be spilled, all available opportunities to promote the well-being of all should be exploited. Secondly, it refers to an idea of unanimity. If some one is worse off in the move from one situation to another, the Pareto criterion gives this person a strict veto power to stop the move. But on the other hand, Pareto efficiency suffers from an important drawback. Typically there are many Pareto efficient allocations and the concept is not able of ranking them. In particular, two Pareto efficient allocations can be completely different in terms of distribution of resources between the agents.

Therefore, it seems worthwhile to take a more agnostic stance and work within a framework, which is sufficiently flexible to accommodate for different normative approaches on the societal objective to be pursued. One possibility is to look for the maximum of a general objective function, which is increasing in the individual (here: national) utility levels. This implies that we model the international bargaining process as a maximization exercise:

$$(11) \qquad \max \quad W\left(U_1, U_2, \ldots, U_n\right)$$

where the U_i stands for the individual countries' utilities (given by the discounted sum of consumption levels for instance). Many interpretations can be given to this maximization exercise:

1. The first interpretation is the most traditional one, in which we see W as an ethically inspired social welfare function. Interpreted in this way, the predictive power of the maximization exercise may be minimal. Indeed, there is no international social planner that could implement the results. However, the exercise has an obvious normative appeal, because it yields the optimal solution for an ethical observer with a given set of value judgments. And we can do sensitivity analysis with respect to these value judgements, in particular the degree of world income inequality aversion.

2. An interesting special case is the choice of a linear specification, in which:

$$(12) \qquad W = \sum_{i \in N} \lambda_i U_i$$

It is well known in economic theory that under certain conditions, the full set of Pareto efficient points can be found as the solution to this maximization exercise by varying the λ-vector. This is interesting, since rational and well-informed negotiators will reach a point on the Pareto-frontier as the result of their negotiations. Of course, additional assumptions will be needed to choose between the different points on the frontier. But the maximization with different values for λ gives us an insight into the characteristics of the bargaining space.

3. Finally, W can be seen as a shortcut to compute many traditional game-theoretic solutions to the bargaining process. All cooperative and non-cooperative solutions leading to a Pareto efficient result are special cases of expression (12) and will be recovered in our framework for a specific choice of the λ-vector. In general the specification of W may reflect the differential power positions of the different countries. This interpretation readily suggests itself for linear specification in (12), which can be derived as the outcome of a bargaining game. The λ-vector then immediately gives the weights in a social power function.
4. The maximization approach also allows for inverse optimum calculations. For a given environmental problem and a proposed burden sharing, it is an interesting exercise to solve for the weights λ that would make this agreement an optimal choice. This gives us an idea of the bargaining or ethical weights that were implicitly used during the negotiations. We will do an attempt in this direction for the 1997 Kyoto Protocol on the reduction of greenhouse gases emissions in section 4 of this article.

Finally, it is important to recognize that the set of Pareto efficient or socially optimal points will be dependent on the instruments which are available during the negotiations. The description of the externality problem therefore has to be completed by a specification of the set of available instruments. Because we want to concentrate in this paper on the equity/efficiency trade-off in its pure form, we will neglect the problem of implementation and assume that the set of instruments to be considered during the negotiations consists of the vector of individual abatement levels $\left\{R_i^t\right\}$. Hence, negotiations bear on abatement efforts directly and not on policy instruments like, for instance emission taxes or tradable permits. Moreover, to illustrate the importance of monetary side payments, we will assume that these are not available.

3.3 Under-provision of environmental quality in the laissez faire scenario

In the absence of side payments, the socially optimal allocation for the international environmental externality problem can be described as the allocation that maximizes the global society's objective function (11) subject to the individual countries' resource balance conditions (7) and capital accumulation processes (2). Like before temperature change and emissions are given by the relationships (5) and (3) respectively. Maximizing with respect to the capital stock gives rise to the following necessary condition:

$$(13) \qquad \frac{\partial F_i^t}{\partial K_i^t}\left[1-\sigma_i^t \frac{\sum_{j\in N}\lambda_j \kappa_j^t}{\lambda_i}\right]-\delta=\rho \qquad \forall i,\forall t$$

in which $\kappa_j^t=\sum_{\tau=t}^{\Omega}\frac{D_j'\left(\Delta T^\tau\right)}{\left[1+\rho\right]^{\tau-t+1}}\frac{\partial h^\tau}{\partial E_j^t}$ stands like before for the weighted sum of all future marginal damages to country *j* from emitting one additional unit of emissions at time *t*.

Maximizing with respect to the emission abatement effort gives rise to the condition:

$$(14) \qquad \lambda_i C_i'\left(r_i^t\right)=\sum_{j\in N}\lambda_j \kappa_j^t \qquad \forall i,\forall t$$

The interpretation of the latter expressions is more instructive for the specific case in which all countries are given the same social welfare weight $\lambda_i=\lambda_j \quad \forall i,j\in N$. Under this assumption the two necessary conditions become:

$$(15) \qquad \frac{\partial F_i^t}{\partial K_i^t}\left[1-\sigma_i^t \sum_{j\in N}\kappa_j^t\right]-\delta=\rho \qquad \forall i,\forall t$$

$$(16) \qquad C_i'\left(r_i^t\right)=\sum_{j\in N}\kappa_j^t \qquad \forall i,\forall t$$

The latter condition is the well-known Samuelson condition for the optimal provision of the global public good "emission abatement". It says two things. First, emissions are to be cut back to the point where marginal abatement costs equal the total sum of all marginal damages over all countries. Secondly, reduction efforts are to be allocated such that marginal abatement costs are equal across all countries (the right hand side of (16) is the same for all countries).

Comparing conditions (13) and (14) to the corresponding conditions (9) and (10) for the non-cooperative equilibrium clearly shows the origin of the externality problem. In the socially optimal allocation, individual emission reduction is a function of the *sum over all countries* of the individual valuations of future climate change damages $\sum_{j\in N}\kappa_j^t$. In contrast, in the non-cooperative equilibrium, only individual damage valuations κ_i^t are taken into account in every country's decision rule. This observation leads us to say that the non-cooperative laissez-faire equilibrium is characterized by *incomplete internalisation of external effects*.

3.4 Cost efficiency and the role of equity considerations

When we attach equal weights to all countries, the socially optimal burden sharing should be cost-efficient: equation (16) shows that the marginal cost of abatement (per ton of GHG emissions) is the same for all countries and equals the sum of the private valuation of future climate change damages. Cost efficiency implies that it is impossible to decrease the total cost of the global emission reduction target by altering the burden sharing. If countries differ in abatement costs, cost efficiency will require some differentiation of abatement targets. In particular, low cost countries should be asked to perform relatively more effort than high cost countries. In the case of global warming such cost-efficient allocation would require greater efforts from poorer countries (developing countries or economies in transition) since they are often characterised by relatively low abatement costs. In that case there is a direct conflict between equity and efficiency considerations.

But attaching equal weight to each country is not so straightforward as it may seem at first sight. It implies that we attach the same value to an additional dollar of consumption to a rich and to a poor country. Many people object to this and argue that unequal weights, favouring poor countries, are to be used in social optimisation exercises. Using unequal weights, condition (14) shows that cost efficiency is no longer required. Countries with a high marginal social value of consumption λ_i (for instance poor countries with a low initial capital stock or countries with a strong bargaining position) are required to abate less. The reason is intuitively obvious: because the international community has no financial redistribution instrument at its disposal, differences in abatement costs are used to influence the distribution of welfare.

We now draw the following conclusions for the socially optimal solution:

- Compared to the laissez faire non-cooperative equilibrium, individual emission restrictions in the socially optimal solution should be a function of the total (weighted) sum over all countries of all expected future climate change damages. This principle is called *full internalisation of external damages*.
- When equal welfare weights are used for all countries, the socially optimal burden sharing leads to equalization of marginal emission abatement costs. This principle is called *cost efficiency* and means that overall emission reduction cannot be achieved at a lower total cost by reshuffling the emission reduction burden.
- When one cares about equity, unequal weights favouring the poor should be used. The resulting socially optimal burden sharing will be more lenient regards poor countries or countries with high bargaining power and vice versa. Hence, equity or political power considerations can justify deviations from the cost efficiency prescription (if there are no compensating financial transfers available to achieve distributional objectives).

3.5 Participation constraints and free riding

Although by definition, total welfare in the socially optimal case will be higher than total welfare in the non-cooperative equilibrium (indeed, the socially optimal allocation maximises the societal objective function and it is therefore by definition higher than the value of this objective function evaluated at the laissez-faire equilibrium), it need not necessarily be the case that every individual country gains from moving from the non-cooperative to the socially optimal outcome. An example in the case of global warming is provided by the former Soviet Union. It is generally believed that GHG emission abatement costs are low in the former Soviet Union because of its obsolete industrial infrastructure. Replacing old coal fired power plants by new more efficient gas-fired power plants is a relatively cheap way to save emissions in those countries. On the other hand, the former Soviet Union is also believed to be only very little vulnerable to climate change damage. Hence, in a non-cooperative Nash equilibrium, it would chose for a relatively low abatement effort. However, in a cost efficient global burden sharing arrangement, the former Soviet Union would be asked to perform a lot of cheap emission reduction. It should be clear that without monetary compensation, the former Soviet Union is bound to lose in a cost efficient international climate agreement since it has to perform a lot of abatement effort and the resulting costs are only partially compensated for by moderate savings on climate change damages.

Due to the lack of a world authority with sufficient coercive power, individual countries have strong veto power in international environmental agreements. It is clear that a rational self-interested country will never join an agreement that would leave it worse-off compared to a feasible and credible outside option. Producing GHG emission abatement is essentially a public good provision problem. An important characteristic of public goods is that no one can be excluded from enjoying its benefits, regardless of the fact that he or she contributed or not to financing the public good. For every country, it is beneficial if other countries undertake more abatement effort since higher reduction efforts by one country imply lower climate change damages for everyone. This observation gives rise to so-called *free riding behaviour*: it is in every countries self interest to enjoy the benefits of reduced climate change without contributing to the required abatement effort.

The public good nature of global environmental protection restricts the set of feasible solutions. A solution is only feasible if it is voluntarily acceptable for all its signatories. There is a huge body of literature devoted to this problem of voluntary international environmental agreements (**see International cooperation to resolve international pollution problems**) that we will not survey in this contribution. It is sufficient for our framework that there exists for every country some reservation utility level $\bar{U}_i$ that it might obtain using a credibly free-riding strategy. The precise content of these reservation utility levels will depend upon the game-theoretic equilibrium or stability concept one uses to describe voluntary international environmental agreements. We can now state the voluntary participation constraints of all countries as follows:

(17) $$U_i \geq \bar{U}_i \quad \forall i$$

In order to be implemented by means of a voluntary international environmental agreement, the burden sharing should result in a utility allocation that respects the participation constraints as expressed by (17). The participation constraints should be included as additional constraints in the global maximization problem. Depending on what equilibrium concept is chosen to determine the relevant reservation utility levels $\bar{U}_i$, (for instance, the noncooperative Nash equilibrium introduced higher can under some conditions be interpreted as a fall back position since every country can guarantee itself this outcome by refusing all cooperation) the global maximisation problem might become infeasible. In particular, if the joint sum of claims by all countries exceeds the maximal value of the societal objective function, there does not exist a voluntary international environmental agreement sustaining full cooperation of all countries. Partial cooperation is then the only way out, see also **International cooperation to resolve international pollution problems.**

The social optimisation problem including participation constraints leads to very similar necessary conditions as the conditions (13) and (14) before. One only has to replace the original weights λ_i by new weights that take into account the shadow price of the participation constraints of the individual countries. Let us define $\tilde{\lambda}_i = \lambda_i + \psi_i$ as the new weights. If for a particular country, the participation constraint is non-binding, the shadow value ψ_i of this constraint is zero and the new weight coincides with the old weight: $\tilde{\lambda}_i = \lambda_i$. If however, the participation constraint binds for one or more countries, their bargaining weights increase.

The effect of the participation constraints can be illustrated using the following picture. The vertical and horizontal axes give the utility level of the (presently) poor South and rich North respectively. The inner curve gives the production possibilities in the case where no greenhouse policies are implemented, the outer curve gives the production possibilities after the socially optimal level of emission abatement has been achieved. It is clear that the utility levels have to be interpreted in a dynamic sense: they capture both actual and future material welfare levels. The exact position and curvature of the production possibility curves depend on all the elements (production technology, abatement costs, climate change damages etc.) described in section 2.

Point A on the inner curve is given by the laissez-faire Nash equilibrium and entails an extremely unequal distribution of utility. The parallel welfare indifference lines (i.e. lines of equal social welfare) denoted by W^0, W^1 and W^2 represent a social welfare or bargaining power function in the spirit of the previous section. The unrestricted social optimum would be in point B with a much more equal distribution of utility. In order to go from point A to point B two steps have to be taken: first, greenhouse policies have to be implemented to bring us from the inner to the outer curve; second, an international income redistribution has to take place (and, in fact, the rich will have to give up part of their high living standard).

It is also easy to show in this figure the consequences of the absence of an international government. If we are in point A and if the North is driven by self-interest it will never accept a policy which would bring its living standard below the one enjoyed in point A. An analogous reasoning holds for the South and therefore, the absence of a world government (hence the fact that we have to rely on voluntary international agreements) limits us to agreements that improve for both North and South on point A. These points are found to the right and above point A, in the shaded area in Figure 1.

Figure 1: Participation constraints and social optimal allocations

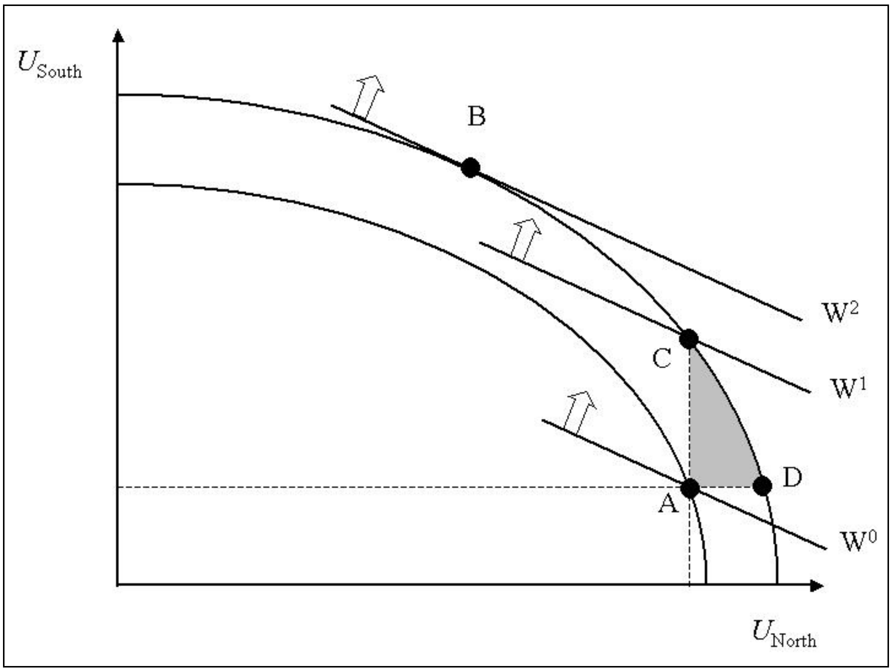

Figure 1 is a strong simplification of the complex reality but it allows us to illustrate clearly some basic points. First, in a situation without world government and where nations are driven by self-interest, the best we can hope for are Pareto improving agreements bringing us somewhere on the segment CD. It is important to realise, however, that this restriction has nothing to do with justice but only follows from the power and the pursuit of self-interest by a large part of the world. It is better therefore to speak about participation constraints that put restrictions on the achievable outcomes.

Secondly, the "best" (from a social point of view) while at the same time feasible agreement is easily defined: it is found in point C. Given the extremely unequal starting positions the gains from cooperation should go completely to the presently poor South. Note that this does not imply that the North has to give up part of its living standard. It enjoys the same utility level in the status quo-position A and in the socially optimal and feasible situation C.

Third, a number of very specific proposals have been made of so-called "just solutions" to the burden sharing problem in the context of greenhouse negotiations. Examples of such proposals are: equal percentage reduction targets, equal per capita emission reductions, equal per capita cost shares etcetera. These proposals assume that the burden sharing problem is a "positive sum-game", in which all participants would gain if an agreement could be reached.

The problem then becomes one of dividing the gains from cooperation or one of finding the "just" point on the line segment CD in Figure 1. Seen from this perspective, our suggestion to pick point C in Figure 1 might seem a very extreme one, in which all the gains go to the poorest partner or, alternatively, all efforts are borne by the richest partner. But the perspective is misleading, because it tends to neglect the grossly unjust starting positions of the different partners in the negotiations. One cannot reasonably talk about a "just" distribution of efforts or gains from greenhouse negotiations, if one does not place these negotiations within the broader context of the unequal international income distribution. Partial justice is a mirage if the broader context is extremely unjust!

- For every country, it is beneficial if other countries undertake more abatement effort. This observation gives rise to the so-called *free riding behaviour*: it is in every countries self interest to enjoy the benefits of reduced climate change without contributing to the required abatement effort.
- Because of the global public bad character of many transboundary pollution problems, countries often can make credible threats to abstain from environmental protection. Every candidate environmental agreement must therefore take into account participation constraints making the agreement voluntarily acceptable to all its signatories.
- Participation constraints put limits on the choice of socially optimal levels of emission reduction and burden sharing agreements. The higher the aspiration level, i.e. the utility level it can ensure itself by playing a credible non-cooperative strategy, of a particular country, the higher its power in international environmental negotiations.
- A socially desirable or "just" burden sharing arrangement should take into account absolute differences in starting positions of the participating countries in order to avoid the mirage of partial justice.

4. CONFRONTING THEORY AND REALITY FOR THE CASE OF GLOBAL WARMING

In this section we will confront the theoretical conclusions derived in the previous section with the on-going climate negotiations in the framework of the UNFCCC. In particular, we will make a tentative evaluation of the efficiency and equity content of the Kyoto Protocol.

4.1 Cost and benefit estimates for GHG emission control

During the last decade, a lot of empirical studies have been published in the economic literature giving more insight into the precise pattern of winners and losers for the global warming problem. The literature is huge and we will not attempt to survey it in the context of this article. We refer the interested reader to the bibliography at the end of this article. Instead, we will distinguish between two broad classes of empirical approaches that have been used in the context of climate change and we will summarize the main findings.

Medium term climate policy evaluation models

First, there is a huge and growing body of literature on the precise implementation issues of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and in particular the famous 1997 Kyoto Protocol. Many reports, books and research papers address the burden sharing and the flexible mechanisms that were agreed upon in the subsequent Conferences of the Parties (CoPs) of the UNFCCC. Also the ratification difficulties, in particular the recent US withdrawal from the agreement, and the provisions for carbon sinks, are given ample attention in the literature. Mostly, the analyses use some medium term (typically a time horizon up to 2030) global partial or general equilibrium model to assess the impacts of the Kyoto Protocol on energy consumption and production and to draw a picture of the winners and losers of climate politics. The main conclusions of this type of models can be summarized as follows:

- For all Annex B countries (i.e. the countries that accepted quantified emission ceilings in the Kyoto Protocol), total gross costs to achieve the Kyoto targets (without emission trading) are relatively modest, in most cases even below 1% of GDP in 2010.
- Significant cost savings can be achieved by using flexible mechanisms like emission trading. The size of the cost savings increases as the size of the emission trading market is expanding. Unrestricted global trading of carbon entitlements would cut compliance costs by half or more.
- Most studies predict that there will be only a handful of permit exporters among Annex B countries, in particular the Russian Federation and Ukraine. This gives rise to serious concerns about strategic monopoly behaviour by these countries.
- Recent developments like the US withdrawal and the provisions for carbon sinks will cause the emission reduction target to be completely eroded.

Integrated assessment climate-economy models

Integrated assessment models are models that combine a description of the economy with a stylised representation of the physical environment (the global carbon cycle and climate system in the case of global warming) in order to achieve an explicit feedback between the economic and climate variables. Definitely the most famous (and probably one of the earliest) example of integrated assessment models applied to global warming is the DICE (Dynamic Integrated Climate Economy) model by William D. Nordhaus. The typical time horizon used in integrated assessment models stretches out to several centuries because the coupled climate model is characterized by a high degree of inertia and long time lags before physical consequences of today's emissions become visible. In order to study the regional differences and stability of international environmental agreements on climate change, integrated assessment models had to be regionalized. The single most influential model in this category is the RICE (Regional Integrated Climate Economy) model by Nordhaus and Yang. The model we used in section 2 of this paper is a simplified version of the RICE model. In particular we have ignored international trade issues in order to focus more deeply on the equity-efficiency trade off in climate change. The main results from these integrated assessment models can be summarized as follows:

- Due to extreme long time lags and inertia of the global carbon cycle and climate system it takes several decades (up to a century even) before the effect of current GHG emission reductions on global climate change becomes noticeable. In order to have a non-negligible impact on future temperature change, drastic and sustained GHG emissions cuts are necessary.
- The stakes in controlling GHG emissions are small compared to overall economic activity. In the absence of strong non-linear climate effects (e.g. a fast meltdown of a major part of the Antarctic ice sheet or a sudden change in the Atlantic conveyer belt), gross GDP losses for the world as a whole range between 1 and 2% for the 21st century.
- Most developing countries tend to win relatively more than high-income countries when moving from a non-cooperative laissez-faire scenario to a coordinated global welfare maximizing climate policy. This is mainly due to their assumed high vulnerability to climate change damages.

4.2 Main elements of the Kyoto Protocol

The Kyoto Protocol is the result of a political agreement achieved during the Third Conference of the Parties of the UNFCCC held in Kyoto in December 1997. The protocol was signed by 84 countries and will come into force after official ratification by at least 55 countries whose joint emissions represent at least 55% of the total emissions by the protocol members that have accepted quantified emission ceilings. By now (July 12, 2002) 75 countries have ratified the text representing some 36% of the emissions. Hence, the first prerequisite has been met but a few major emitters still have to submit the text to their national parliament for official approval before the Protocol can come into force.

The main objective of the 1997 Kyoto Protocol is to achieve a reduction of about 5% of GHG emissions by the industrialized signatories. Only 39 countries have accepted quantified emission reduction objectives, they are listed in an annex to the protocol and are therefore often referred to as the Annex B countries. The reduction obligations for the most important countries are as follows: European Union: -8%, USA: -7%, Japan and Canada: -6%, New Zealand, Russian Federation and Ukraine: 0%, Norway: +1%, Australia: +8%. The reduction obligations bear on 6 GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6).

An important element of the Kyoto Protocol is the provision for so-called flexibility instruments that enable countries to exchange emission reduction obligations. The main instruments are international emission trading, bubbles, joint implementation and clean development mechanism. We will shortly describe the instruments, more detailed information is available on the web page of the UNFCCC (see glossary).

- *International emission trading (Article 17)*: Annex B countries can engage in international exchange of emission rights in order to meet their national targets. Countries emitting less than their ceiling can sell the surplus to countries that have difficulties meeting their target. The protocol is vague on the precise modalities of the emission trading instruments, the details were left to be filled out during subsequent CoPs.

- *Bubbles (Article 4)*: under certain conditions, a group of countries can agree to reallocate their emission ceilings among each other while respecting their overall target. This instrument was used by the European Union to redistribute the overall EU target of –8% over the different EU member states. The internal burden sharing agreement within the EU has resulted in highly differentiated abatement requirements ranging from –21% for Germany and Denmark to +25% for Greece and +27% for Portugal (percentage changes with respect to 1990 emission levels).

- *Joint implementation (Article 6)*: is an instrument enabling the exchange of emission targets between two Annex B countries on the basis of a verifiable project. This instrument makes it possible for, say the EU, to buy emission reduction in the Russian Federation. The instrument requires that the emission reduction is verifiable in the sense that it should result from a concrete project like the modernization of an existing power plant.
- *Clean Development Mechanism (Article 12)*: is also a project based instrument for bilateral exchange of emission reductions. But in contrast to JI, CDM can be used to buy emission reduction from non-Annex B signatories of the Kyoto Protocol. This instrument would for instance allow Japan to buy emission reduction in China if Japan were to finance the construction of a combined heat and power plant on Chinese territory.

4.3 Evaluation of the Kyoto Protocol

We now turn to an evaluation of the Kyoto Protocol from an economic point of view.

Figure 2: Marginal abatement cost functions and Kyoto objectives

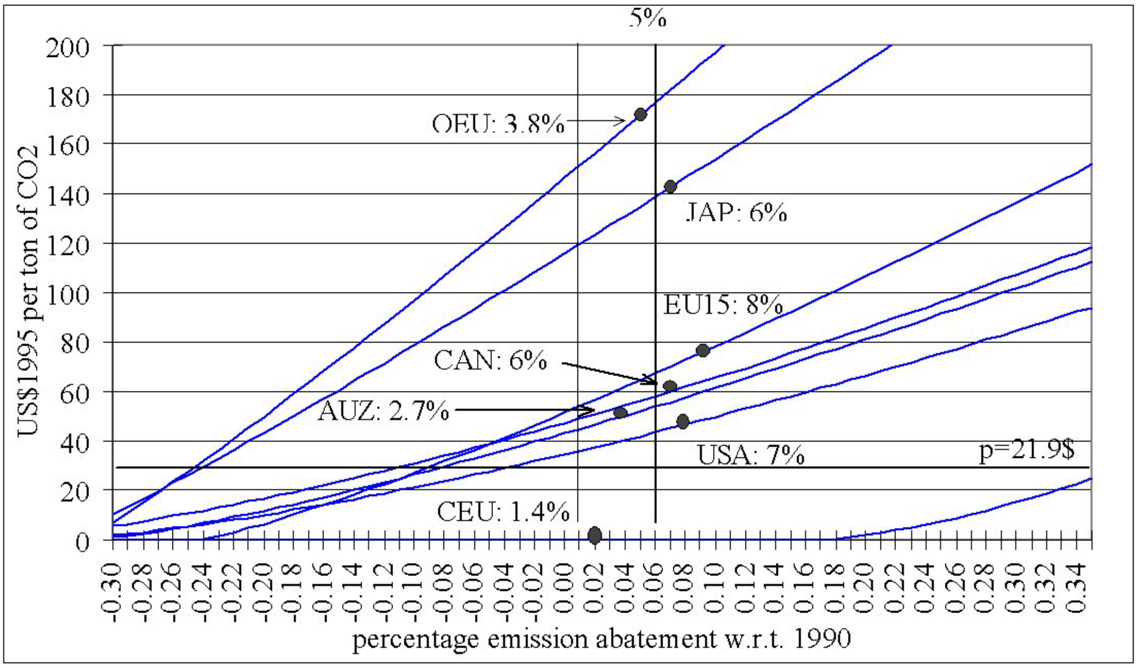

Figure taken from Eyckmans, van Steenberghe and Van Regemorter (2001). Is Kyoto fatally flawed? An analysis with McGEM.
AUZ: Australia and New Zealand,
CAN: Canada,
CEU: Central and Eastern Europe (including former Soviet republics),
EU15: European Union,
JAP: Japan,
OEU: Iceland, Norway and Switzerland,
USA: United States of America.

Figure 2 shows marginal abatement cost functions for the main countries/regions that have adopted quantified emission reduction targets in the 1997 Kyoto Protocol. The horizontal axis depicts percentage emission reduction with respect to 1990 emissions, the vertical axis measures the cost in US$ per ton of CO_2. The solid black dots in Figure 2 represent these Kyoto objectives for the different countries. The curves represent an estimate of the marginal carbon emission abatement cost functions for the different regions. They are drawn relative to 1990 emissions and their intersection with the horizontal axis gives the estimate of emission growth between 1990 and 2010 in the business-as-usual scenario without explicit climate policy. For instance, emissions of the EU15 are projected to increase by approximately 24% with respect to 1990 emission levels. Central and Eastern European (CEU) emissions are projected to decrease by some 18% in BAU.

We can use Figure 2 to make a tentative evaluation of the equity content of the 1997 Kyoto Protocol. We will look successively at the overall Kyoto reduction target, the Kyoto burden sharing, the flexible mechanisms, the recent US withdrawal and finally, provisions for carbon sinks.

Overall Kyoto emission reduction target

All emission restrictions agreed upon in the Kyoto Protocol add up to approximately 5% emission reduction compared to 1990 emissions *for the Annex B group of countries*. It is however important to realize that the share of Annex B emission in the global total amounts to some two thirds (a share that is projected to decrease strongly to about 60% or even 50% by 2010). Hence about one third of world emissions are not subject to emission ceilings and can grow unchecked. Moreover, these emissions come from major fast growing developing economies like China, India, Brazil and others. Therefore, the effect of the Kyoto Protocol on world emissions is only to slow down a little the staggering emission growth pace.

In the Kyoto Protocol text there is no explicit reference to arguments that would justify this 5% reduction in terms of expected future climate change damages. Only political compromising seems to have played in this case. For a more explicit long-term climate policy objective we can however refer to the general principle of the UNFCCC:

> *The ultimate objective of this Convention [...] is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*
>
> *1992 UNFCCC, Article 2*

This text gives some guiding principle that could be used to formulate a long term GHG global emission ceiling. There is no specific reference to an extended cost-benefit analysis but the general idea of a trade off between ecological sustainability and economic development is present.

From the experience with integrated climate-economy models it should be clear however that the Kyoto reduction commitment is by far insufficient to attain the atmospheric concentration stabilization objective laid down in the 1992 UNFCCC. Far more drastic and sustained emissions cuts are required. Participation by the US and by major fast growing developing economies like China, India and Brazil in future commitment periods is therefore indispensable.

Kyoto burden sharing agreement
The 39 countries listed in the Annex B to the Protocol's text all committed to a quantified emission limitation. Among those Annex B countries there is remarkably little differentiation of emission targets. Most Annex B countries have adopted reductions ranging between 0 and minus 8%, which is relatively little compared to projected emission growth between 1990 and 2010. Therefore, without flexible mechanisms, differences of marginal costs are very large. Figure 2 reveals that they range from more than 170 \$/ton CO_2 for Scandinavian countries to about 50 \$/ton CO_2 for USA or even zero for the former Soviet Union. The latter countries do not have to make real efforts to cut back emissions since they have been assigned an emission ceiling exceeding even the highest emissions projections for 2010. It is therefore said that the former Soviet Union has been assigned "hot air".

How can we link these observations on marginal abatement costs in the actual Kyoto Protocol to the theoretical analysis of the previous section? We can clearly state that the cost efficiency has not been a primary objective in the original 1997 Kyoto Protocol burden sharing agreement. The targets have been differentiated little and some low cost countries have been completely exempted. One can interpret the relatively low marginal costs implied by the Kyoto burden sharing for the USA, Canada and Australia as a clear sign of their relatively strong bargaining power. In terms of expression (14), these countries had relatively high power weights λ_i. On the other hand, one might argue that the exemption of quantified emission ceilings of most developing countries are of a more ethically inspired nature. These countries were apparently characterized by relatively high weights λ_i as well but this has probably little to do with their strong bargaining position. It is more likely that the gentle treatment of the developing countries is an expression of another basic general principle of the UNFCCC:

> *The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.*
>
> *UNFCCC, Article 3, first paragraph*

Flexible mechanisms

Under pressure of the US delegation, the original Kyoto protocol text made very general provisions for so-called flexible mechanisms that would allow countries to exchange emission reductions with each other under different modalities. However the precise details of these mechanisms were left to subsequent CoPs and it has proven to be very difficult to get to a consensus on this issue. By now, the mechanisms have clearly been defined and institutions are being designed or set up to make them function.

Theoretically, the flexible mechanisms should make it possible to achieve the overall emission reduction target at a far lower cost. Rational countries with relatively high abatement costs will choose to buy emission credits instead of reducing emissions domestically if the world market price of permits is lower than their domestic marginal abatement cost. Because of this fact, emission trading will lead to a convergence of marginal abatement costs and hence to a more cost efficient allocation of abatement efforts. The fact that allowing for exchanges of emission reduction credits will lead to substantial cost savings and more equal distribution of marginal costs is well established in both the theoretical an empirical environmental economics literature.

In addition, these flexible mechanisms have important implications for the burden sharing agreement since they will generate substantial flows of financial resources from permit importers to permit exporters. Since most studies predict that there will be only one important permit exporter, in particular the former Soviet republics, there will be a substantial flow of money towards those countries. Also the developing countries can take advantage from the flexible mechanisms. Although they are not entitled to participate in emissions trading or JI, they can join in CDM projects with Annex B countries. This gives developing countries an opportunity to invest in more energy efficient power plants for instance and having an industrialized country pay for this investment. In general, the flexible mechanisms will generate transfers that will to a great extent flow from richer towards poorer signatories of the Protocol and will therefore improve upon the current unequal world income distribution.

US withdrawal

Another important development in the post-Kyoto negotiations was the refusal in March 2001 of President Bush to submit the Protocol for approval by the US Senate. From a descriptive point of view, we can argue that apparently, the participation constraint for the US was not satisfied in the original Kyoto Protocol (even including the flexible mechanisms). For subsequent commitment periods, it is crucial to get the US on board again but it is clear that the American bargaining position is much stronger than before. Any burden sharing proposal for the second commitment period (2013-2017) will have to take into account the US participation constraint as a prerequisite to achieve a larger coalition of countries engaging in GHG emission reductions.

Carbon Sinks

A final remark concerns the use of carbon sinks. Both activities resorting under Article 3.3 (afforestation and deforestation) and Article 3.4 (revegetation, forest management, cropland management, grazing land management) can give rise to net additions to the assigned amount of an Annex B country. There are in principle no limits on Article 3.3 activities, except for the general principles of eligibility, reporting etc. For Article 3.4 activities however, and in particular for forest management, data are largely lacking and negotiators were afraid that the sinks credits would erode the general emission targets of the Kyoto Protocol. Therefore, the amount of credits that can be obtained from forest management activities under Article 3.4 has been limited to the total of all credits obtained under Article 3.3 activities. Further activities of forest management eligible under Article 3.4 should be such that total forest management activities of each party do not exceed the levels listed in the so-called Annex Z of the CoP 6bis (Bonn) agreement. In general the carbon sinks will make it easier for countries to meet their emission targets. Moreover, countries with relatively strong bargaining positions like for instance Canada, Japan and Australia have managed to get the most generous carbon sinks credits.

5 CONCLUSION AND OUTLOOK TO THE FUTURE

Starting point for this article is the observation that arguments concerning equity and the international distribution of income are likely to play an important role in multilateral negotiations on environmental agreements. In the first part of the paper we have used a maximization framework to illustrate the differences between the non-cooperative or laissez-faire outcome and socially desirable solutions for transboundary pollution problems. This maximization framework allows for ethical or bargaining power interpretations and can be used to solve the inverse optimum solution, i.e. compute the social weights implied by a given carbon emission abatement agreement. We have shown that if one care about world income distribution, the traditional cost-efficient burden sharing need not be socially optimal. The Samuelson rule for the optimal provision of greenhouse gas abatement is replaced by the condition that weighted marginal abatement costs should be equalised across all countries. We illustrated how participation constraints have an important impact on the set of achievable socially optimal outcomes.

In a second part we have interpreted the 1992 UNFCCC and the 1997 Kyoto Protocol in the light of the theoretical model. We are able to explain many of the features of the actual burden sharing agreement in terms of power or ethically inspired arguments.

As a general conclusion and outlook to the future we would like to argue the following. First, it is a mistake to talk about equity in the distribution of emission reduction targets in an international environmental agreement if one neglects the unequal world income distribution in the background. We should warn against a "mirage of partial justice" that seeks to find equitable solutions by isolating the burden sharing problem from the underlying unequal starting positions. The evidence in the framework of climate change negotiations seems to confirm this point. Developing countries and economies in transition were apparently given some respite for the time being.

Secondly, participation constraints matter a lot and are to be included as constraints in the burden sharing negotiations. Again, the reality of climate negotiations seems to confirm this. Countries with strong bargaining power managed to negotiate relatively low emission reduction obligations whereas other, that felt that they could do better by not respecting the Protocol, simply left the room. Therefore, for the negotiations on the burden sharing in subsequent commitment periods of the Kyoto Protocol the prime objective should be to ensure that participation constraints of the major emitters are satisfied first, equity considerations should come into play second.

Finally, it is important to stress that the 1997 Kyoto Protocol is only a first step on the way towards an effective long-term climate policy. The protocol only covers a first commitment period ranging from 2008 towards 2012. After the difficult Conferences of the Parties in The Hague, Bonn and Marrakech, and after the US withdrawal, no single expert will deny that the emission reduction content of the Protocol has been eroded completely. It is more important to recognize however that the general framework set out by the 1992 UNFCCC has survived.

The UNFCCC has laid the rails for a long-term climate policy whereas the Kyoto protocol is only a first train testing the tracks. Subsequent trains are to be put on the rails and the real emission reduction, including participation by developing countries, is the real challenge in the decades of climate negotiations to come.

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