Economic and Environmental Impacts of Various Climate Policy Scenarios

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Abstract

The purpose of the paper is to compare various climate policies within a cost-benefit analysis framework in a world divided in five regional groups. Global cooperation is compared with non cooperative behavior and partial cooperation (coalition of countries cooperating while others do not) in terms of economic and environmental impacts. The next step is to deviate from an economic analysis of cooperative and non cooperative policies to study the impacts of various hypothetical climate policies as well as policies discussed from the Earth Summit to the Kyoto Protocol: uniform reduction, different stabilization policies and policies associated with the Kyoto Protocol. This more pragmatic issue, which is less aimed at efficiency, demonstrates that an "ideal,, scenario does not exist, because economic and environmental objectives do not necessarily coincide. It also shows that the Kyoto Protocol was probably more directed towards an environmental rather than an economic goal and examines an alternative option for retaining the participation of the United Sates.

Keywords: climate policies, cost-benefit analysis, efficiency, effectiveness

1. Introduction

By burning fossil fuels and increasing the rate of deforestation, man is interfering with the natural greenhouse effect. Greenhouse gas concentration is steadily rising and climate models estimate that before the end of next century, concentration would have doubled compared to pre-industrial levels and the earth might be 1.5 to 4.5 degrees warmer (with a 2.5 degrees value used in this study) at the equilibrium. The consequences of such a predicted warming include sea level rise; changes in agricultural practices and in vegetation, an increase in the frequency of tropical storms and hurricanes and an impact on human health. Public awareness has steadily increased over the past decade with the writing of the Framework Convention on Climate Change signed in Rio in 1992 and the Kyoto Protocol signed in Japan in 1997.

A standard framework of analysis for environmental economists is the theory of externalities which is based on welfare economics. Since the emission of greenhouse gases in the atmosphere causes a public bad (negative public good) externality, therefore generating a market failure, the "laissez-faire" solution is unable to generate the optimal amount of pollution. The externality can only be internalized through cooperation between the actors as no country can impose a policy to another independent nation.

After a brief explanation of the cost-benefit formulation (section 2), the economic and environmental impacts of worldwide cooperation versus a non cooperative behavior will be compared in section 3. Since the early discussions about emissions reduction at the Earth summit in 1992, some countries showed a willingness to curtail emissions while others did not; partial cooperative scenarios, and their impacts on regional and global abatement as well as welfare, are thus examined in section 4. Section 5 departs from the economic analysis of relations between rational cooperative and non cooperative regions to evaluate the impacts of various political scenarios, among which the Kyoto Protocol with and without the participation of the United States. General conclusions are then derived in the final section.

2. Cost-Benefit Analysis

Any model is based on hypotheses, any computation is based on existing data and any hypothesis or data used can and does influence the final results. This is also the case in this study and as a precautionary measure in interpreting the final results, the five main hypotheses used in the cost-benefit formulation and their impacts on the results are stressed below.

The first hypothesis is the division of the world into five groups: the United Sates of America (USA), the other OECD – Organization for Economic Cooperation and Development - countries (OOECD), the former Soviet Union (FSU), China and the rest of the world (ROW). This can be considered too limited or arbitrary, but it is mostly due to the availability of data even though some recent models have a few additional players (Nordhaus and Yang, 1996). Another issue is that the ROW group is very heterogeneous because it includes nations ranging from oil exporting countries and poor African nations to small Pacific islands, all of which have obviously very different views about global warming. It certainly prevents the generalization of a conclusion for the ROW group to all its members. Nonetheless, each group is an important polluter and the main purpose is to understand the interactions between these large players in terms of cooperation possibilities, environmental effort and net benefit.

The analysis spans over 110 years (from 1990 to 2100) to underscore the fact that climate change is a long term problem. However, the cost-benefit formulations are not time dependent. As a matter of fact, regional business-as-usual emissions ($E^B_{j,t}$) in billion tons of carbon estimated until 2100 by Manne (1993) are used to compute yearly emissions of a restrictive policy ($E_{j,t}$) and the abatement that automatically follows ($\Theta_{j,t}= E^B_{j,t}- E_{j,t}$); these data are then summed up over all t periods to get global and regional emissions[1] and abatement of a particular environmental policy. Similarly, regional abatement costs and benefits of emissions reduction are computed over time and are then discounted and summed to get a global figure expressed in terms of global and regional abatement. If a fully dynamic issue might give different results, a static formulation is nevertheless acceptable as the Kyoto Protocol stresses target emissions to be reached at some period of time instead of emission trajectories requiring a dynamic analysis (Chander et al., 1999).

Costs are defined as losses from a country's own output[2] – C_j=f(Θ_j) –, benefits are computed as damages prevented from a global climate policy – B_j=f(Θ) and they are also assumed to be additive: ($B=\sum_j B_j$ and $C=\sum_j C_j$). Various cost data have been computed by other authors (Manne and Richels, 1992; OECD, 1993; Nordhaus, 1994) and benefits are derived from, among others, damage at CO_2 doubling, previously computed as well (Fankhauser and Pearce, 1994). As in all modeling exercises, results of the cost-benefit analysis can only be credible if the estimated data are credible. This suggests some caution in the interpretation of the results. The static cost-benefit formulation derived from dynamic data follows Hamaide and Boland (2000) and is stated formally in the appendix.

It is also assumed that a doubling of CO_2 concentration with respect to pre-industrial levels will bring about a rise in temperature of 2.5 degrees Celsius ($\nu=2.5$) at equilibrium. This is a rather standard hypothesis (Cline, 1992) and a change of half a degree would only slightly advance or delay the regional benefits without having a significant impact on the aggregate static cost-benefit analysis.

The discount rate is set at a uniform 2 percent by hypothesis. Any change in the discount rate would obviously modify the results, but a rate of 2 to 3 percent is generally what is recommended in such a study (Lind, 1990; Nordhaus, 1994). Even if the idea of a positive discount rate can be criticized on grounds of intergenerational equity, that argument should be dealt with out of the rigid procedures of discounting. Indeed, accepting the idea of monetizing costs and benefits implicitly includes the idea of time preference, which, added to the fact that Gross World Product (GWP) is expected to increase over time, calls for a non zero discount rate.

In summary, the cost-benefit formulation presented in the appendix is based on various assumptions that can be justified and on available data knowing that other hypotheses and data might somewhat modify the conclusions. Nevertheless, as long as data used are correct, this simple formulation may give an interesting insight on the economic impact of a climate policy (magnitude of the net benefit or net cost) as well as on the environmental impact (magnitude of the effort required).

3. Cooperative and Non-Cooperative Behavior

Economically speaking, because no supra-national organization can force all regions to adopt a particular policy, it will be up to each individual entity to decide either to behave rationally without taking into account the impact of its pollution on others or to cooperate with the other players so as to arrive at a socially desired outcome and internalize the externality.

The non cooperative strategy implies that, by ignoring the impact of its emission policy on others, region j maximizes its own welfare (net benefit) while taking as given the behavior of the other players:

$$\underset{\Theta_j}{\text{Max}} W_j = \left[\alpha_j \Theta + \sigma_j \Theta^2 - \left(\lambda_j \Theta_j + \mu_j \Theta_j^2\right)\right] \forall j = 1, 2, \ldots N \qquad (1)$$

which implies an optimal emission reduction Θ_j such that $C_j^{'}(\Theta_j) = B_j^{'}(\Theta)$, knowing that $C_j(\Theta_j) = \lambda_j \Theta_j + \mu_j \Theta_j^2$ et $B_j(\Theta) = \alpha_j \Theta + \sigma_j \Theta^2$ (see Appendix).

Economic efficiency is reached when all countries act as if they are a single entity thereby internalizing the externality by maximizing their global net benefit:

$$\underset{\Theta_1, \ldots, \Theta_N}{\text{Max}} \quad W = \left[\alpha\Theta + \sigma\Theta^2 - \sum_{i=1}^{N} \left(\lambda_i \Theta_i + \mu_i \Theta_i^2\right)\right] \qquad (2)$$

with $\alpha = \Sigma_i \alpha_i$ and $\sigma = \Sigma_i \sigma_i$. The first order conditions equalize regional marginal abatement cost with social marginal abatement benefit ($C_j^{'}(\Theta_j) = B^{'}(\Theta)$) which gives a

Pareto optimal abatement where it is not possible to increase someone's net benefit without reducing someone else's own welfare.

Regional optimal abatement in aggregate value between today and the year 2100 (Θ_j) as well as in percentage of reduction ($R_j=\Theta_j/E_j$) and net payoffs ($W_j=B_j-C_j$) are displayed in Table I for the cooperative and non cooperative cases.

Table I

The optimal non cooperative abatement is very small (5.8 percent of global emissions). Even though every player derives a positive net payoff, the developed world is the major winner since the USA is free riding and 95 percent of the effort is undertaken by non OECD countries. Rational individualistic behavior may thus be optimal in an economic sense, but it is certainly not equitable to developing nations.

The cooperative formulation obviously induces a higher abatement (16.6 percent) and a higher social welfare but is again placing the burden on developing countries[3] For full cooperation to be feasible, every player must be at least as well off as in non cooperation. Therefore, China and the USA need to be compensated which is theoretically possible since the extra amount earned by all the other players is higher than the amount China and the USA lose from cooperating. Nevertheless, compensating the USA and restricting developing nations while being more lenient with rich countries makes full cooperation a politically unacceptable scenario in reality.

As full cooperation is unfair and as decided in the Kyoto Protocol, it is clear that some form of imperfect cooperation is taking place. Technically, this issue can be handled in two different ways. On one hand, economic theory enables to study the outcome of coalitions playing against rational individualistic nations. On the other hand, pragmatic policy analysis can use hypothetical (or current) partially cooperative policies as a starting point, no matter its economic efficiency or inefficiency, to derive net payoffs and the resulting abatement. Both methods are considered, the former being discussed in the next section and the latter in the subsequent sections.

3. Partial Cooperation: Coalitions

In a partially cooperative framework, each non cooperative entity *m* maximizes its own net benefit (equation 3) whereas cooperative nations *y* maximize their coalition's welfare (equation 4).

$$\underset{\Theta_m}{\text{Max}}\ W_m = \left[\alpha_m\Theta + \sigma_m\Theta^2 - \left(\lambda_m\Theta_m + \mu_m\Theta_m^2\right)\right] \quad \forall m = 1,2,...M \tag{3}$$

$$\underset{\Theta_1,...,\Theta_Y}{\text{Max}}\ W^* = \sum_{y=1}^{Y} \left[\alpha_y\Theta + \sigma_y\Theta^2 - \left(\lambda_y\Theta_y + \mu_y\Theta_y^2\right)\right] \quad \forall y = 1,2,...,Y \tag{4}$$

and $M+Y=N$.

The first order conditions of equations 3 and 4 can be computed and give a unique solution as there are respectively *M* and *Y* equations with *M* and *Y* unknowns. After simplifying and rearranging the terms, the optimal abatements for the *M* non cooperative countries are

$$\Theta_m = \frac{\lambda_m - \alpha_m}{2(\sigma_m - \mu_m)} - \frac{\sigma_m}{\sigma_m - \mu_m}\left(\sum_{s \neq m}^{M} \Theta_s\right) \qquad \forall m = 1,2,..,M \tag{5}$$

and the optimal emissions reduction for countries in the coalition are

$$\Theta_y = \frac{\lambda_y - \alpha - 2\sigma \sum_{x \neq y}^{Y} \left(\frac{\lambda_y - \lambda_x}{2\mu_x}\right)}{2(\sigma - \mu_y) + 2\sigma\mu_y \sum_{x \neq y}^{Y} \frac{1}{\mu_x}} \qquad \forall y = 1,2,..,Y \tag{6}$$

Various coalitions will be compared based on the following hypotheses. First, because of the European behavior since the early stages of the negotiation process, it is assumed that they are always part of the cooperative coalition and that their view is taken up by all members of the OOECD region (which is not obvious in reality as the umbrella group represented by Canada, Australia and Japan may be more inclined to follow the USA rather than Europe). Second, for equity reasons, it is assumed that the ROW and China will not agree to restrain their emissions unless the developed world (USA and OOECD) as well as FSU do the same. Excluding the full cooperative solution explained earlier, five coalitions respect the above hypotheses. They are i)USA+OOECD+FSU+ROW, ii) USA+OOECD+FSU+China, iii) USA+OOECD+FSU – that is approximately the Annex I countries of the Kyoto Protocol - , iv) USA+OOECD and v) OOECD+FSU. Each of these coalitions should be taken as examples and the purpose of the exercise is to see the impact of a particular coalition on global abatement and social as well as regional welfare. Therefore, coalition stability is not tested.

Table II displays disaggregated net payoffs (W_j) and percentage of abatement (R_j) for all five scenarios as well as the resulting social welfare:

Table II

In the first scenario, all industrialized countries, as well as developing nations, having an incentive to cooperate in terms of payoff form a cooperative coalition whereas China is free riding. As ROW is the only cooperating region with a low abatement cost, it has to abate the most for compensating the non participation of China, the other low abatement cost country. Only one player in the coalition, the USA, is worse off but social welfare being much larger than at full non cooperation, it can theoretically be compensated by the other players, including developing countries. Common sense therefore requires to qualify this scenario, requiring transfer from the South to the North to hold, as inapplicable – politically unacceptable - in reality.

If China agrees to form a coalition with Annex I countries while the ROW abates up to the point where its own marginal benefit is equal to its own marginal cost, global abatement and social welfare are the highest of all current scenarios, which is intuitively expected since China has low abatement cost and ROW makes the largest effort of all players at non cooperation while deriving net benefit. China and the USA are obviously worse off than at non cooperation as they both were free riding. Side payments are again theoretically possible but would require a transfer from the South to the North ruled out in the previous scenario for equity reason and by common sense.

The third scenario is a coalition made of the USA, the other OECD countries and the Former Soviet Union. It brings about emissions reduction and a global welfare that are both about half way between the cooperative and the non cooperative solutions. For the coalition to be sustained, OECD countries must be compensated which would again require a South – North transfer and cannot stand in practice. But this scenario is in the line of thought of the Kyoto Protocol with the difference that Annex I countries are asked to cooperate as if they are a single entity instead of reaching a target abatement within a certain time frame while the other nations are asked to be individually rational (that is equating their own marginal benefit and cost) instead of being able to free ride. If Annex I countries agree not to be compensated (which again is in the line of thought of the Kyoto Protocol), this behavior is now turned around and may be considered as a unilateral transfer from the North to the South aimed at reducing environmental externalities in the South[4] as advocated by Yang (1999) while poor countries would follow their Nash strategy instead of a no-control policy[5].

The last two scenarios are worse in all perspectives: lower abatement, lower social welfare, more South – North transfers; and they are thus not credible from a political perspective. For illustration purpose, the “Kyoto without the USA„ scenario in a cooperative versus non cooperative framework would lower global abatement by more than 20 percent compared to the USA participation (10.9 versus 8.4 percent abatement) and lead them to free ride.

In conclusion, with the hypotheses posed at the beginning of this section, even though all scenarios are economically viable with transfer payments, none is politically acceptable as the burden is disproportionately placed on developing nations in terms of abatement and transfer payments. And, when analyzing the "Kyoto coalition„ it is only when the economic efficiency objective of the scenario, reducing global emissions by 10.9 percent, is set aside or in other words, if transfer payments are canceled and the OECD countries accept to bear the costs of cooperation, that it may perhaps become politically viable or politically open for discussion as it implies that China would free ride but that the other developing countries would abate the amount equating their own marginal benefits and costs.

4. Uniform Reduction

The purpose of this section and the following ones is less the economic analysis than the pragmatic analysis. Knowing that a global or partial optimum is rarely reached, the idea is to evaluate and compare the economic impact and the resulting abatement of various policies that have been discussed over the years since the Earth Summit or that are purely hypothetical. The policy options examined are a uniform abatement strategy and other strategies in the Kyoto Protocol and the Framework Convention of Climate Change line of thought with and without constraints on non OECD countries.

Command-and-Control policies are the most widely used tools in environmental policies and one of the most common option is the uniform reduction; this is why it is considered here. The best uniform target is obviously a policy bringing about the optimal cooperative abatement, that is 16.6 percent reduction. This is indeed confirmed by finding a value of Θ for which $B'(\Theta)=C'(\Theta)$. The curve $C(\Theta)$ is found by fitting a line through $\sum_j C_j(\Theta_j)$ which is depicted in Figure 1[6]. Resulting regional net benefits are displayed in Table III.

Table III

Figure 1

By imposing a uniform abatement and not a reduction based on regional cost curves, the burden is now shared evenly instead on being mostly placed on developing nations. Resulting welfare is therefore distributed differently and to the advantage of poor nations (China is even better off than in free riding because of its negative abatement cost shape during the first percentages of abatement). The loss of USA which is not free riding as in non cooperation can easily be compensated by transfer payments from the OOECD alone for the scenario to hold theoretically.

In summary, social welfare is slightly smaller than at full cooperation (6136<6305) but still very high and appropriated at more than 80 percent by poor nations; the three non OECD groups are better off than at non cooperation, that is better off than if each individual entity behaves rationally and the burden is shared evenly (but the feasibility of a reduction for poor countries is yet to be analyzed and accepted politically). And since a uniform percentage reduction is the easiest method to implement, it could have been a good alternative to the targets set out in Kyoto.

5. Other Policy Scenarios

Uniform abatement has not received a large approval during the negotiations as it has been estimated that the first and largest step should be done by developed countries. For that reason, it is interesting to compare the impact of stabilizing emissions (and not concentration) in OECD countries with and without restraints on non OECD nations as originally proposed in the Framework Convention of Climate Change in 1992 and decreasing emissions in the same countries compared to 1990 levels as proposed in the Kyoto Protocol.

5.1. THE STABILIZATION SCENARIOS[7]

The three scenarios are as such: i) stabilization of OECD emissions at their 1990 levels while non OECD emissions go "business-as-usual„, b) stabilization of OECD emissions at their 1990 levels with a ceiling of twice 1990 emissions on non-OECD countries and c) stabilization of OECD emissions at their 1990 levels with a uniform reduction of 16.6 percent in the developing world as of 2010. Regional net payoffs and abatement efforts are displayed in Table IV.

Table IV

Stabilizing emissions in OECD countries imposes a very large net cost to the rich world whereas non-OECD countries derive benefits from the abatement in the developed nations. If China and ROW would obviously agree on such a policy, FSU would nevertheless have had an incentive to abate up to its non cooperative point and not to completely free ride as the cost of its first emissions restrictions is negative – but that is not taken into account here as the hypothesis is that non OECD countries go business-as-usual. On the whole, social welfare, is largely negative (*W*=-5028) for a global abatement of 17.1 percent, which is larger than at full cooperation. However, the environmental advantage of that policy needs to be traded off against the global economic loss it brings about.

The second policy option restricts emissions of non-OECD countries below twice their 1990 levels until 2100. The former Soviet Union does not undertake any abatement because in business-as-usual conditions, they less than double their emissions over the 110 year period. China and ROW are however very much restricted in their CO_2 release because of their rapidly increasing emission trend in business-as-usual conditions (65 and 53 percent reduction respectively). Therefore, they incur very large costs and have negative net payoffs. The larger FSU payoff with respect to non cooperative equilibrium and the improvement of USA and OOECD with respect to the previous policy is far from being sufficient to compensate the loss of China and ROW; hence, social welfare is even more negative than in the previous scenario where OECD acts by itself. On the environmental side, this is a seemingly favorable option since there is a global emissions cut of 49.4 percent but it would be done at the expense of developing countries which is thus inapplicable in policy negotiations.

It has been shown above (section 4) that a uniform emissions reduction of 16.6 percent is an interesting candidate from an environmental and economic standpoint while sharing the burden of CO_2 curtailment evenly. If the OECD nations still stabilize their emissions at 1990 levels by 2010 and the three other players agree to reduce 16.6 percent of their emissions from 2010, while staying at that level thereafter, social welfare becomes slightly positive (*W*=35) and abatement reaches 27.6 percent. This scenario, while being economically inefficient, has various advantages. First, OECD's net payoffs are less negative than if they act alone. Second, the burden of abatement is placed on rich nations who need to reduce about half of their emissions. And third, non-OECD's payoffs are all positive, contrary to the previous option and even higher than at cooperative and non cooperative equilibriums.

5.2. THE KYOTO SCENARIOS

Instead of stabilizing emissions in developed nations, the Kyoto Protocol went further and asked for emission reductions in the OECD and stabilization in the FSU. Three additional scenarios are considered. The fourth one is the original Kyoto Protocol, the fifth one is the Protocol with a free riding behavior from the USA and the last one is the Protocol with a uniform reduction of 16.6 percent in the developing world as of 2010. Emission reductions and net benefits of these three scenarios are illustrated in Table V.

Table V

The original Kyoto Protocol negotiated in 1997 is aimed at reducing emissions by 5.2 percent in 2008-2012 in Annex I countries while the others go business-as-usual. The FSU needs to curtail its emissions back to their 1990 levels by 2010 (as an average of the period 2008-2012), and it is assumed that they remain constant thereafter. Emissions in the USA and OOECD have to decrease by 7 and 7.3 percent respectively compared to 1990 levels and remain constant thereafter. The choice of the OOECD target (7.3 percent) is calibrated in such a way that this number brings about a 5.2 percent reduction in Annex I countries by 2010 as mentioned in the Protocol. Compared to the stabilization scenarios, OECD countries make a larger reduction and their net loss is thus worsening. FSU is losing as well in stabilizing its emissions because of the shape of its cost curve (negative in the early phases of abatement and then very steep: OECD, 1993). Non OECD countries, being unrestricted, get large positive net payoffs but it is not sufficient to cover the loss of the other regions and therefore, social welfare is largely negative. Economically speaking, computations show that the Kyoto Protocol is not an acceptable solution. Nonetheless, the environmental impact of the Kyoto Protocol is fairly large as it brings about a 20.8 percent reduction in global emissions: it is more than at full cooperation (16.6 percent) and about twice as much than the FSU-OECD coalition (10.9 percent). The justification of the negotiated Protocol may therefore have been a tradeoff of economic efficiency for environmental purposes.

In 2001, the Bush administration refused to ratify the Protocol. If this can make economic sense, looking at the rough numbers exposed above, it did change the global picture and the global idea behind the Protocol. First, the Protocol was denied its apparent prime importance for environmental objectives rather than economic efficiency. Then, the free riding position of the USA might have induced the other OECD nations to follow that lead as they would again bear an even larger burden (their net loss increases from 6510 to 7425) than expected and it might also have induced the FSU to be reluctant about stabilizing its emissions while the richest country in the world would not. Because of the worldwide outrage following its decision and for the remaining Protocol not to break apart, the USA is proposing an alternative solution for itself but some large OECD countries (the umbrella group: Canada, Australia and Japan) are still hesitating about their final position on the ratification. Provided that the USA is free riding – which is their non cooperative economic result - but that the umbrella group is ratifying the Protocol, and that the FSU nevertheless accepts to stabilize its emissions, global curtailment is now down to 12.5 percent, that is about 40 percent less than the original expected environmental impact.

One of the most common request from US negotiators concerns the participation of developing countries (Shogren, 2000) as they may be the largest emitters of greenhouse gases later in the century. An alternative solution may therefore be to have the USA sticking with the previous administration's target of the Kyoto Protocol while attracting developing countries to agree to a uniform reduction compared to business-as-usual levels without compromising both their welfare and their future development.

The proposal is a mix of the Kyoto Protocol for the OECD only and the 16.6 percent uniform reduction as of 2010 - so that targets become enforceable for the whole world at the same time - for the others. In this hypothetical scenario, the largest burden is obviously borne by OECD nations, FSU would derive positive net payoffs contrary to its Kyoto objective and because of the expected shape of their cost curves, developing countries should not theoretically be harmed by these restrictions as their payoffs would be larger than at non cooperation. Social loss is greatly reduced compared to the original Protocol (1142<6495) and it is the most aggressive environmental policy as global emissions are substantially reduced by an overall 28.7 percent.

6. Conclusion

Negotiations over the past ten years demonstrate that worldwide cooperation for reducing emissions is currently unrealistic, but that some nations agree to cooperate for combating global warming. Various possible coalitions have been examined and their economic behavior shows that not a single scenario does respect a fairness standpoint between the developed and the developing worlds, as the latter has to abate much more than the former and is even supposed to give away part of its extra benefit to rich nations.

Other policies are then examined knowing that they may not be economically efficient. The simplest (and most often implemented) case is a uniform reduction. A 16.6 percent emissions restraint in each region seems an interesting policy candidate as the effort is non trivial and the largely positive payoffs are distributed favorably to developing countries which can be an incentive for their approval. The stabilization scenarios are rather aggressive from an environmental standpoint, but bring about a large welfare loss, and are therefore economically inefficient (only when non OECD nations are constrained by a uniform reduction is global welfare becoming positive).

If the United States were to participate in the Kyoto Protocol, the very large environmental impact (20.8 percent reduction) would be reached at the expense of a big welfare loss for the parties involved in the Protocol and with a welfare gain for free riding developing countries. In this regard, the US reaction of dropping its participation from the Protocol is not too surprising, and the reaction of Europe to nevertheless implement it can be considered as a good example of environmental conscientiousness. It remains to be seen which party the FSU and the umbrella group will follow; but all other things being equal, the Protocol without the United States has a much more limited environmental impact for a still bad economic efficiency.

As the USA has shown that it will not untie environmental and economic objectives, contrary to Europe, without an important exogenous stimulus, some developing countries participation may be needed for achieving the largest environmental reduction from the largest possible group. In that sense, the emission targets of the Kyoto Protocol for OECD countries coupled with a uniform reduction elsewhere large enough to have an environmental impact and small enough for not hindering development may be a credible alternative. Without being efficient, this scenario may hold both from its effectiveness -large reduction in emissions - and its burden sharing rule -most burden on OECD countries but participation of non OECD countries.

Appendix : Equations of the cost-benefit model

Benefit computations

- Step 1 : estimate CO_2 concentration in time ($\Gamma(t)$) based on regional emission data ($E_j(t)$) :

$$\Gamma(t+1) = A\Gamma(t) + (\eta\varepsilon E(t)) \tag{A1}$$

where A is the extinction parameter associated with CO_2 ocean absorption, η is the airborne fraction of CO_2, ε converts billion tons of carbon equivalent in ppmv – parts per million in volume - and $E(t)=\_{j}E_j(t)$. A, η and ε are known parameters.

- Step 2 : estimate equilibrium warming :

$$\Delta T(t) = \alpha \ln \Gamma(t) - \beta \tag{A2}$$

where α and β are calibrated so that $\Delta T(t)=0$ at pre-industrial levels, and by hypothesis, $\Delta T(t) = \nu = 2.5$ at CO_2 doubling

- Step 3 : compute regional damages in time ($D_j(\mathrm{t})$) :

$$D_j(t) = \Omega_j Q_j(t)\left[\frac{\Delta T(t)}{\upsilon}\right]^{\gamma} \tag{A3}$$

where $Q_j(t)$ is the regional GDP, $\_{j}$, the scale of regional damages at CO_2 doubling (Fankhauser et Pearce, 1994) and γ a non linear parameter.

- Step 4 : compute benefits as damages prevented when restricting greenhouse gas emissions Θ :

$$B_j^{\Theta}(t) = D_j^{B}(t) - D_j^{\Theta}(t) \qquad \text{(A4)}$$

where *B* stands for “business-as-usual„.

- Step 5 : regional benefits from 1990 to 2100 are then discounted back to 1990 and summed over the whole period to get a number corresponding to a particular emissions reduction policy. The same computations are repeated for all abatement percentages so as to get a series of points in the benefit versus abatement space. The best fit function going through these points is :

$$B_j(\Theta) = \alpha_j \Theta + \sigma_j \Theta^2 \qquad \text{(A5)}$$

Cost computations

Regional abatement costs $C_j(t)$ are estimated based on existing data (OECD, 1993 ; Nordhaus, 1994) for various abatement levels Θ. As in step 5 of benefit computations, they are then discounted back to 1990 and summed up, yielding one point per abatement policy in the cost versus abatement space. This is done for various policies and a curve is fitted through the points. The best fit is obtained by equation A6:

$$C_j(\Theta_j) = \lambda_j \Theta_j + \mu_j \Theta_j^2 \qquad \text{(A6)}$$

Optimal cooperative and non cooperative abatement

The first order conditions of equation 1 under non negativity constraints give the optimal non cooperative abatement, which is , after simplifications

$$\Theta_j = \frac{\lambda_j - \alpha_j}{2(\sigma_j - \mu_j)} - \frac{\sigma_j}{\sigma_j - \mu_j}\left(\sum_{i \neq j} \Theta_i\right) \quad \forall j = 1,2,...,N \qquad \text{(A7)}$$

First order conditions of equation 2 shows optimal regional cooperative abatement, or, after rearrangement:

$$\Theta_j = \frac{\lambda_j - \alpha - 2\sigma \sum_{i \neq j}\left(\frac{\lambda_j - \lambda_i}{2\mu_i}\right)}{2(\sigma - \mu_j) + 2\sigma\mu_j \sum_{i \neq j}(1/\mu_i)} \quad \forall j = 1,2,..,N \qquad \text{(A8)}$$

Optimal abatement computed with equations A7 and A8 are displayed in Table I. Net benefit, W_j is then calculated by replacing the values of Θ_j in equations 1 and 2.

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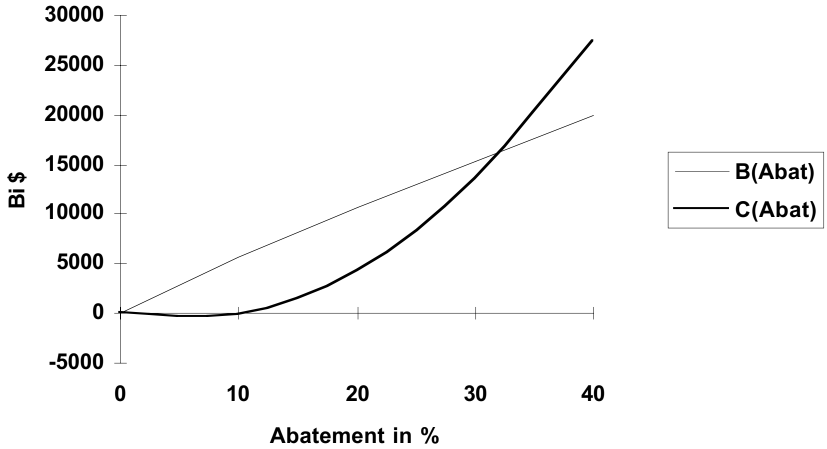

Figure 1: Global Benefit Cost Comparison

	Non cooperative Θ_j	W_j non coop	Cooperative Θ_j	W_j coop
USA	0% (0)	354	14.7% (44)	282
OOECD	1.5% (5)	624	14.5% (46)	1105
FSU	10.9% (18)	1139	13.3% (22)	1468
China	0% (0)	667	17.6% (64)	637
ROW	12.8% (82)	1571	18.9% (121)	2813
Total	5.8% (105)	4355	16.6% (297)	6305

Table I: Optimal Cooperative and Non-Cooperative Abatement (Θ_j) in Percentage of Regional Emissions and in Billion Tons of Carbon over 1990-2100 (in Parentheses) and Resulting Net Payoffs (W_j) in Billions of 1990 US Dollars.

	Coal 1		Coal 2		Coal 3		Coal 4		Coal 5	
	W_j	R_j	W_j	R_j	W_j	R_j	W_j	R_j	W_j	R_j
US	85	14.7	133	14.8	-68	14.8	-82	14.9	511	0
OOECD	746	14.4	835	14.5	469	14.5	444	14.6	196	15.5
FSU	1345	13.7	1374	13.7	1257	13.8	1312	10.9	1168	13.8
China	1518	0	528	16.1	1240	0	1215	0	962	0
ROW	2073	19.9	3064	12.8	2475	12.8	2435	12.8	2035	12.8
W,R	5767	13.4	5934	14.2	5374	10.9	5324	10.7	4872	8.4

Table II: Regional Net Payoffs (W_j) - in Bi. USD - and Emissions Reductions (R_j) - in Percentage - for Various Coalitions.

	$R_j = R =$ 0.166		Non Coop	W_j coop
	W_j	Θ_j	W_j	W_j
USA	113	50	354	282
OOECD	906	53	624	1105
FSU	1244	27	1139	1468
China	735	61	667	637
ROW	3139	106	1571	2813
W, Θ	6136	297	4355	6305

Table III: Regional Net Payoffs (W_j) - in Bi. USD - and Abatement (Θ_j) - in Bi. Tons of Carbon - of Uniform Emissions Reduction

	case 1			Case 2			case 3		
	W_j	Θ_j	R_j	W_j	Θ_j	R_j	W_j	Θ_j	R_j
USA	-4654	139	46.5	-2761	139	46.5	-4033	139	46.5
OOECD	-5983	167	52.2	-2474	167	52.2	-4838	167	52.2
FSU	612	0	0	1762	0	0	1740	25	15.3
China	1940	0	0	-5554	236	64.5	2015	59	16.2
ROW	3057	0	0	-6668	341	53.3	5151	103	16.4
W,Θ,R	-5028	306	17.1	-15695	883	49.4	35	493	27.6

<u>Table IV</u>: Regional Net Payoffs (W_j) - in Bi. USD -, Abatement (Θ_j) - in Bi. T. of C - and Emissions Reductions (R_j) - in Percentage - for Various Stabilization Policies

	case 4			case 5			case 6		
	W_j	Θ_j	R_j	W_j	Θ_j	R_j	W_j	Θ_j	R_j
USA	-5231	149	49.8	753	0	0	-4764	149	49.8
OOECD	-6510	177	55.3	-7425	177	55.3	-5648	177	55.3
FSU	-823	46	28.2	-1121	46	28.2	1780	25	15.3
China	2353	0	0	1417	0	0	2139	59	16.2
ROW	3716	0	0	2229	0	0	5351	103	16.4
W,Θ,R	-6495	372	20.8	-4147	223	12.5	-1142	513	28.7

<u>Table V</u>: Regional Net Payoffs (W_j) - in Bi. USD -, Abatement (Θ_j) - in Bi. T. of C - and Emissions Reductions (R_j) - in Percentage - for Various Kyoto Policies

[1] The sum of business-as-usual emissions from 1990 to 2100 in billion (10^9) tons of carbon equivalent are respectively 299, 321, 163, 365 and 640 for the USA, the other OECD countries, the former Soviet Union, China and the rest of the world.

[2] They do not take into account any flexibility mechanism as proposed by the Kyoto Protocol

[3] This is due to their relatively lower abatement cost curves as estimated by Manne and Richels (1992) and OECD (1993)

[4] Except in China since its non cooperative solution is to abate nothing

[5] An important difference is that in Yang (1999), under certain conditions, unilateral transfers improves both the welfare of the North and global welfare.

[6] Figure 1 can be drawn as a single net benefit curve as in Boyd et al. (1995).

[7] Emission restrictions in all this section's scenarios are computed with respect to business-as-usual levels as of 2010 like established in the Kyoto Protocol. Therefore, no emission in any case is restricted from 1990 and 2010.