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BURDEN SHARING RULES IN POST-KYOTO STRATEGIES : A GENERAL EQUILIBRIUM EVALUATION BASED ON THE GREEN MODEL.

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1. Introduction.

1. Efficiency principles have inspired the Protocol signed in Kyoto in December 1997 by Annex 1 countries. However, this Protocol - if it ever comes into force - will do little to stabilise the concentration of Greenhouse Gases (GHGs) in the atmosphere. A divide between rich and poor countries blocks post-Kyoto negotiations so that any extension of the Protocol to non-Annex 1 countries is unlikely as long as equity principles are not brought explicitly into consideration. The dilemma is the following: stabilisation of concentration cannot be achieved without participation of developing countries and developing countries are not willing to collaborate as long as they consider that rich countries bear the responsibility of the building-up of GHGs in the atmosphere. A priority task in this context is to identify rules of entry and burden sharing in order to extend the Kyoto Protocol in a way compatible with long-term objectives of concentration stabilisation.

2. This paper assesses a number of alternative burden-sharing rules (based on income per capita, emissions per capita and historical emissions) by using the GREEN world General Equilibrium model developed by the OECD Secretariat. The rules are not aimed to correspond to any likely outcome of the current climate change negotiations. Rather, they should better be considered as archetypal cases to be used as guiding benchmarks in evaluating the outcome of forthcoming negotiations.

3. These rules are defined such as to comply with more or less ambitious targets of stabilisation of carbon concentration in the atmosphere over the next two hundred years. The assessment of the alternative rules involves the aggregate and regional economic costs, the amount of carbon trading generated and the amount of complementary side payments that would be needed if rich countries need to « bribe » the support of developing countries by compensating them for their potential losses.

4. Three main results emerge. First, for OECD countries, it looks less costly to adapt to climate change than to “bribe” support of developing countries by compensating them for their costs of abating emissions. Second, assuming that emissions trading will be subject to restrictions (as in the current version of the Protocol), any burden-sharing rule implying some kind of egalitarian target (either for income or emissions per capita) would be more costly than equiproportionate emission reductions (equivalent to a “grandfathering” allocation of permits). Thus, any future extension of the Kyoto Protocol based on the

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principle of an equal and universal emission right or implying some "ability to pay"principle will require a well-functioning and unrestricted trading system to keep its global cost low. Third, in designing future burden-sharing rules, there is a trade-off between market-based and direct distributive mechanisms. Some rules - based, for instance, on the « ability to pay » or some « equal per capita emissions target » - have a high market-based distributive potential as they generate high amounts of emissions trading. However, they also generate huge inter-country/region monetary flows that, in practice, may prove unfeasible to handle or, at least, will induce high transaction costs. The alternative - based on a "grandfathering" allocation of the emissions - is less costly but also has a lower market-based distributive potential and would need to be supplemented by large side payments. However, the political feasibility of large international transfers without clear counterparts is clearly limited, not to say that it should not be recommended from an economic point of view.

2. Long-term dilemma of the Kyoto Protocol.

2.1. Evaluation of the Kyoto Protocol.

Differentiated country-specific targets are at the core of the Protocol.

5. The Protocol signed at Kyoto in October-November 1997 marks the first concrete step of the international effort to reduce GHGs emissions. The central provision of the Protocol is a set of quantified targets for emissions of a number of GHGs over the period 2008-2012 specified for each so-called Annex 1 country. These targets are expressed relative to emissions levels in 1990. All together, Annex 1 countries committed themselves to reduce their emissions by around 5 per cent relative to 1990.

6. The most concrete outcome of the negotiation process in Kyoto is a set of constraints differentiated by country. It is also likely to be the starting point for any further modification or extension of the Protocol. It is however striking how these differentiated targets are unbalanced. Indeed, some countries - like the US - have committed themselves to very substantial abatements (by around 30 per cent relative to unconstrained levels of emissions in 2010). In contrast, the Russian Federation and Ukraine (further referred to as the CIS in the following of this paper) have targets well above their current and projected emissions[2]. Some Annex 1 Parties - such as Iceland, Norway, Australia - were even allowed to increase their emissions relative to 1990 levels.

7. The rationale underlying the allocation of these targets (i.e. the burden-sharing rule of the Kyoto Protocol) is unclear. It clearly contradicts any cost-effectiveness consideration. Indeed, Parties where abatement costs are expected to be higher (Japan, the EU) have to abate more while, in contrast, Parties with low abatement costs - such as the CIS - are not subject to any restriction. Rather, one could arguably consider that the Kyoto commitments have been negotiated such as to generate the larger potential of emissions reallocation among Parties. In other words, the main reason why Parties such as the US and the CIS have signed the treaty is because the former had the possibility to avoid abatement at home by « buying emissions » abroad while the later is expecting substantial benefits from « selling emissions » abroad. In that sense, the Kyoto Protocol combines cost-effectiveness and equity aspects.

8. Although the Protocol has been negotiated with the prospect of generating large amount of emissions trading among Parties, it reflects divergent views among Parties about the use of such trading.

2 The commitment of the CIS is to emissions no higher than their 1990 level.

The Protocol makes provision for three so-called “flexibility mechanisms”: two instruments are “project-based”[3] - the Joint Implementation (JI) and the Clean Development Mechanism (CDM) – while the third instrument is trading of emission rights among Annex 1 Parties. However, the Protocol is not precise on how these instruments should be implemented. Furthermore, it contains restrictions on the use of these mechanisms which, depending on how they are interpreted, may reduce substantially their cost-saving potential. All three mechanisms are described as “supplemental to domestic action” or “additional to any that would otherwise occur”. As for the CDM, it will operate under stronger governance, including supervision by an executive board and certification of emissions reductions by “operational entities”.

9. In the context of the Convention ultimate objective – which is to stabilise climate – the Protocol is best seen as a first step of a long-term effort. In itself, the Protocol will do little to reduce world GHGs emissions and to stabilise their concentration in the atmosphere. At most, it would delay the time at which concentration would exceed the threshold of 550 ppmv - twice the pre-industrial level - by no more than a decade. Furthermore, any further efforts undertaken by Annex 1 countries alone will have virtually no impact on concentration as long as emissions in non-Annex 1 countries grow as they are expected to without any constraint (see OECD(1999)). The explanation is that the share of Annex 1 countries emissions in world emissions is projected to decline rapidly, so that any further measure beyond Kyoto will have no global impact. Simulations made by the IPCC clearly confirm that climate stabilisation imperatively requires active support of non-Annex 1 countries (Wigley et ali., 1997).

2.2. Scope for extension

10. The Kyoto Protocol was agreed on a *voluntary* basis. Thus, one possible rationality underlying the process of climate negotiation may be seen as at least partly related to economic incentives. Against this background, a growing game-theoretic literature analyses the formation of coalitions for environmental objectives such as to combat climate change. These studies provide an analytical background in investigating the ways to extend the Protocol to non-participating countries (see Box 1).

11. In summary, these studies agree that a fully voluntary agreement would comprise at most a small number of signatories and, therefore, be insufficient to stabilise the climate. A main reason for this pessimistic conclusion is the strong incentive for countries to free-ride. The literature also suggests that if carbon leakages are significant, it may be even more difficult to reach wide agreement because incentives to free-ride become stronger. Conversely, the existence of local, ancillary benefits may strengthen the incentives of countries to participate in an agreement. Studies have also identified a number of possibilities to expand this small “self-enforcing” coalition, including by means of transfers to hesitant countries.

3. A framework for assessing burden-sharing rules.

12. Any extension of the Kyoto Protocol will face the problem of identifying a burden-sharing rule, i.e. the rule of allocation of emission reductions or emission rights among participating Parties, involving Annex 1 and non-Annex 1 countries. There is an infinity of ways to share emission reductions or rights among countries in order to reach a given global emission target. The Kyoto Protocol itself involves a

3. As they relate to investment projects rather than emission trading. For instance, if an Annex 1 firm makes an investment in a non-Annex 1 countries resulting in certified emission reductions, the corresponding Annex 1 Party may use this reduction to contribute to compliance with its quantified limitation.

quite uneven sharing of the total abatement effort (see above) which corresponds to a given – although unspecified – rule. The following section identifies criteria to evaluate alternative burden-sharing rule.

3.1. Environmental efficiency .

13. To be consistent with the purpose of the Convention, a rule needs to lead to some kind of stabilisation of GHGs concentration. Indeed, not all rules yield to concentration stabilisation. As a simple example, let us assume the following rule: Annex 1 Parties keep their emissions constant at the levels specified in the Kyoto Protocol while emissions per capita in non-Annex 1 countries cannot exceed the average emissions per capita in Annex 1 countries. As Figures 1 and 2 show, this rule is not compatible with any stabilisation of concentration.

14. Testing the environmental effectiveness of a rule requires to link past and future emissions to concentration. This is usually done by using very large models which simulate the complex linkages between the oceans, the biosphere and the atmosphere. However, for the purpose of this analysis, we have integrated this information into the GREEN model by using reduced-form "response functions". Such kind of function typically expresses how much of the carbon emitted in time t would remain in the atmosphere after a given period of time (see Box 2). In that sense, it allows to calculate how a change in emissions would deviate the future time path of concentration relative to the baseline (which itself is obtained by using a full specification model).

15. Projections made by using the "response functions" from the model of Wigley (1993) yield an unambiguous message about the future efforts to stabilise the concentration of carbon in the atmosphere. Indeed, they indicate that stabilisation will require that, at some point of time - soon or later - world emissions will have to be cut down to very low levels compared to what they are now[4]. These levels would be around 0,5 to 1,5 Gt of carbon emitted per year (against 8 Gt currently emitted). Furthermore, this result holds whatever the level and timing of the stabilisation (see Box 2).

16. For the purpose of this analysis, three emissions profiles are identified which lead to some kind of stabilisation while requiring significant reductions of emissions in Non-Annex 1 countries. These emissions profiles are drawn on the Figure 3 while the Figure 4 shows the resulting concentration time paths as they are projected by using a reduced-form carbon-cycle response function derived from the model of Wigley (1993). The less ambitious option assumes that world emissions continue to grow up to the end of the next century and then fall down drastically. It leads to stabilisation of carbon concentration at 740 ppmv. The medium option simulates a complete stabilisation of world emissions starting from 2030 and implies that concentration stabilises at 550 ppmv. This scenario will be referred to as a « low-cost, high-risk 550 ppmv scenario » as carbon concentration keeps rising fast during the next century, approaching the 550 ppmv threshold by the second half of the next century - a threshold which is often considered as the level at which the risk of experiencing surprises in climate change increases. Finally, the most ambitious scenario assumes drastic reductions of world emissions starting from 2030. As it keeps concentration well below the 550 ppmv over the next century, it will be referred to as a « high-cost, low-risk scenario ». Figures 3 and 4 compare these scenarios with a scenario named "Kyoto for ever" where the Annex 1 emissions are maintained constant after 2012 at the levels of the targets decided in Kyoto while non-Annex 1 emissions remains unconstrained.

[4] Sensitivity analysis performed by using different models of the carbon cycle shows that this result is fairly robust (forthcoming).

3.2. Equity.

17. A given burden-sharing rule is better if it is acceptable to a wide range of countries. Clearly, the use of emission permits increase the probability to satisfy this requirement as the initial allocation of permits can be adjusted such as to compensate the loss incurred by some countries. However, adverse terms-of-effects (in energy-exporting economies, for instance) as well as the fact that some countries are likely to gain from climate change while others would be adversely affected make unlikely to obtain a wide participation through the mean of permits only. Furthermore, permits by themselves do not remove the incentive of free riding[5].

18. Current climate change negotiations consider the possibility that some countries be compensated for their economic losses in order to increase the participation to a global action. Accordingly, two types of inter-country/region transfers will be considered in assessing alternative burden-sharing rules: market-based monetary flows as counterparts of permits transactions and side-payments made to encourage countries to participate to a global action. For each burden-sharing rule, we calculate the amount of payments that Annex 1 countries should make to non-Annex 1 countries on top of the proceeds of permits sales in order to compensate these countries for their economic losses (calculated as the gap between their real income in a scenario with full permits trading and the Business as Usual (BaU) scenario).

3.3. Economic efficiency.

19. In principle, permits trading allows to minimise the aggregate cost of a given emission abatement. Thus, if trading is unrestricted and involves all countries in the world, the aggregate cost depends only on the magnitude of the total abatement. In this case, the choice of the burden-sharing rule does not matter for the aggregate cost, although it clearly matters for the distribution of this cost across countries/regions. However, as mentioned above, the Kyoto Protocol contains restrictions on the use of the « flexibility mechanisms », which will make its extension to non-Annex 1 countries more costly for some burden-sharing rules than for others.

20. Even if all restrictions specified in the Kyoto Protocol were to be removed, there are reasons to consider that some burden-sharing rule will be more costly than others. First, there are very few examples in the real world of perfectly homogeneous traded commodities. One hardly sees why emission rights issued by different countries should be considered as perfect substitutes. Second, transaction costs are likely to be associated with permits transactions and, even more, with projects undertaken under the JI and CDM mechanisms.

3.4. Feasibility.

21. A permit trading in the context of the country-specific targets agreed in the Protocol is likely to generate monetary transfers among countries of an unprecedented size. For instance, simulations using the GREEN model show that emissions trading among Annex 1 countries in the context of the Kyoto Protocol

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[5] Even is the efficiency gains from trading emissions are evenly redistributed, countries have an incentive to remain outside the coalition while getting the environmental benefits of the coalition's action .

would generate an annual monetary flow of 38 billions 1995 $ by 2010, at the benefit exclusively of the Russian Federation and Ukraine. To put this flow into perspective, it corresponds roughly to twice the total liability of Russia to the IMF in 1998. Transfers of that size are likely to have important macro-economic consequences. Setting the institutional framework through which large size permits payments will be made is a challenging task which should urgently deserve attention if the « flexibility mechanisms » have to be implemented in time for the first budget period.

22. The magnitude of the expected permits and/or side payments should be considered in evaluating alternative burden-sharing rules. The underlying idea is that a rule that generates high amount of monetary flows among countries is likely to prove more costly due to transaction and/or administrative costs.

3.5. Definition of three alternative rules.

23. What has been the rule determining the participation to the Kyoto Protocol is unclear. Data suggest that the level of per capita emissions is the underlying criterion for participation. Indeed, all Annex 1 countries belong to the top of the world ranking of countries according to their per capita emissions levels. However, some argue that the level of income per capita explains the participation to the Protocol. Both indicators are correlated any way and can be considered as good candidates for forming a burden-sharing rule. Moreover, it is most likely that the Protocol does not correspond to any of these two rules and is best viewed as a negotiation process combining alternative burden-sharing and tactical considerations[6].

24. In the following of this section, three alternative burden-sharing rules are identified. They are not aimed to serve as a practical basis for any extension of the Protocol. Rather they should be considered as extreme assumptions providing benchmarks in negotiating the participation of non-Annex 1 countries to a global action to reduce GHGs emissions.

"Grandfathering".

25. The simplest rule to begin with is to assume that all countries in the world have to reduce their emissions in the same proportion. Formally, this rule is represented by the following notation :

[6] For instance, the participation of the Russian Federation and Ukraine to the Protocol can be seen as the counterpart of their relatively generous endowment of emission rights in the context of a potential permits market.

Rule 1 : "grandfathering".

World emissions in time t : $\overline{E_t} = (1-g)\cdot E_{t0} \leq E_t$

with g *being the rate of reduction relative to the world emissions in* $t=0$;

E_t *and* E_{t0}, *the unconstrained world emissions in time* t *and* $t0$;

$\overline{E_t}$, *the constrained world emissions in time* t.

Country r emissions in time t : $\overline{E}_{r,t} = share_{r,t0}\cdot\overline{E_t}$ *for* $r=1,N$ *country / regions.*

with $share_{r,t0}$ *being the share of country* r *in world emissions in* $t=0$;

$\overline{E}_{r,t}$, *the constrained emissions of country / region* r *in time* t.

26. This rule is referred as "grandfathering" because - as the above notation makes it clear - it implies that the share of each country in world emissions would remain constant over time. For instance, the total reduction implied by the Kyoto Protocol could have been applied evenly to all countries on a world-wide basis. Some authors - see, for instance, Schmalensee (1996)- have argued that a "broad, then deep" approach would have been better than the "deep, then broad" approach of the current Protocol. A treaty implying less drastic commitments but spread over the entire world community instead of a club of industrialised countries could have been a better starting point for future reductions. In any event, the "grandfathering" rule is for sure not the one that underlies the Kyoto Protocol.

Egalitarian per capita emissions target.

27. COP4 held in Buenos-Aires in November 1998 has evoked the "convergence-equity" principle: namely, that each individual on earth should be entitled with the same amount of emission rights. Accordingly, in extending the Kyoto Protocol, countries should converge to the same amount of emissions per capita. In GREEN, this is simulated by assuming - see the following rule [2] - that Annex 1 countries set their own target and that non-Annex 1 countries cannot exceed the average amount of emissions per capita in Annex 1 countries.

Rule 2 : Equal per capita emissions target.

Annex1 emissions in time t :

$$if\ \ r \in Annex1 \qquad \overline{E}_{r,t} = (1-g)\cdot E_{r,t0} < E_{r,t}$$

with g *being a given rate of reduction;* $E_{r,t}$ *and* $E_{r,t0}$*, the unconstrained emissions in times t and t0; and* $\overline{E}_{r,t}$*, the constrained emissions in time t.*

Non – Annex 1 emissions in time t :

$$if\ \ r \in Non-Annex1 \quad \overline{E}_{r,t} \quad such\ as \quad \frac{\overline{E}_{r,t}}{POP_{r,t}} \le \frac{\overline{E}_{Annex1,t}}{POP_{Annex1,t}}$$

$$and \qquad \overline{E}_{r,t} < E_{r,t}$$

with $\overline{E}_{r,t}$ *and* $\overline{E}_{Annex1,t}$*, being the emissions in the non – Annex1 country r and Annex1 countries;* $POP_{r,t}$ *and* $POP_{Annex1,t}$ *being the populations in the non – Annex1 country r and the Annex1 countries.*

28. In the rule [2], the coefficient γ is calibrated such as to yield a concentration profile compatible with the stabilisation targets defined above. Thus, an important feature of this rule is that, by setting their own emission target, Annex 1 countries determine the degree of participation of non-Annex 1 countries as well as the total amount of emissions abatement.

Ability to Pay

29. The third rule is based on the principle that country participation should be determined by their "Ability to pay": that is their level of income per capita. This is implemented in GREEN by assuming - see the rule [3] - that non-Annex 1 countries join the coalition when their per capita income reaches a threshold expressed as a fraction of the average income per capita in the Annex 1 countries. Furthermore, abatements in non-Annex 1 countries (or permits allowances) are differentiated in proportion of relative per capita income levels[7].

[7] For other uses of a burden-sharing rule based on the ability to pay, see Jacoby, Schmalensee and Sue Wing, 1999

Rule 3 : Ability to Pay.

Annex1 emissions in time t :

$$\text{if } r \in Annex1 \qquad \overline{E}_{r,t} = (1 - g) \cdot E_{r,t0} < E_{r,t}$$

with g being a given rate of reduction; $E_{r,t}$ *and* $E_{r,t0}$*, the unconstrained emissions in times t and t0; and* $\overline{E}_{r,t}$*, the constrained emissions in time t.*

Non – Annex 1 emissions in time t :

$$\text{if } r \in Non - Annex1 \quad and \quad \left(\frac{GDP_{r,t}}{POP_{r,t}}\right) \geq a \left(\frac{GDP_{Annex1,t}}{POP_{Annex1,t}}\right)$$

$$Then \quad \overline{E}_{r,t} = E_{r,t0} \cdot \left(1 + g_{r,t}^{BaU} - e\left(\frac{GDP_{r,t} / POP_{r,t}}{GDP_{NAnnex1,t} / POP_{NAnnex1,t}}\right)\right)$$

with $GDP_{r,t}$, $GDP_{Annex1,t}$ *and* $GDP_{NAnnex1,t}$*, being the GDP of the non – Annex1 country r, of total Annex1 countries and total non – Annex1 countries;* $POP_{r,t}$, $POP_{Annex1,t}$ *and* $POP_{NAnnex1,t}$ *being the populations of the non – Annex1 country r, of the total Annex1 countries and total non - Annex 1 countries;* $g_{r,t}^{BaU}$ *being the emissions growth rate in the Business – as – Usual scenario; and, a and e, being calibrated parameters.*

30. In the rule [3], the decisional parameters are the income per capita threshold α which determines the participation to the coalition and the elasticity ε which differentiates the emissions reductions (expressed as percentage deviations relative to their growth in the BaU) according with country-specific levels of income per capita. These two parameters are calibrated such as to yield concentration profiles compatible with the stabilisation targets defined above

4. Simulation results.

31. The following section discusses the simulation results. Three time profiles of stabilising concentration are considered implying different levels of ambition and risk (the 740 ppmv stabilisation, the « high risk » 550 ppmv stabilisation and the « low risk » 550 ppmv stabilisation). For each of these profiles, abatement commitments or emissions rights endowments are distributed following the three alternative burden-sharing rules defined above: the «grandfathering» rule, the « equal emissions per capita » rule and the « ability to pay » rule. Finally, each of the nine corresponding scenarios are simulated by assuming i) that each country/region meets its commitment individually, i.e. without trading emission rights; ii) that emissions rights are traded among all countries/regions in the world, including those which are not subject to any constraint[8]; and, iii) that, in addition to a world-wide emissions trading situation (thus, taking into account possible proceeds from permits sales), non-Annex 1 countries/regions reporting real income losses relative to the BaU are compensated for the difference by side payments from the Annex 1 countries[9].

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[8] This corresponds to an extension of the CDM assuming that project undertaking has the same characteristics that an unrestricted emission rights trading system.

[9] These payments are calculated « ex post ». Thus, the macro-economic effects of these payments are not taken into account. The question addressed here is what would be the additional transfers if non-Annex 1 countries require side payments equivalent to their economic losses in the context of a world trading system . In that

4.1. The effectiveness of the 'flexibility mechanisms' will determine the economic costs of stabilizing climate.

32. The Figure 5 shows the average real income loss during the period 2010 to 2050[10] in scenarios with full permits trading at the world level. For comparison, the figure also reports the corresponding loss in the "Kyoto for ever" scenario[11]. All three stabilisation options appear much more costly than the extended Kyoto Protocol, which is not surprising given that extending the Protocol comes nowhere near to stabilising concentrations. Average costs increase more than proportionally with the magnitude of the abatements, as would be expected. Stabilising concentrations below 550 ppmv – according with the low risk option - appears fairly costly: it could cost from 0.65 to 0.8 per cent of real income each year on average for the world[12].

33. The Figure 5 verifies that, with full permits trading, the nature of the burden-sharing rule does not matter[13]. Average costs for the world are roughly the same for the three rules, although it is clear that the distribution of these costs across countries may be quite different.

34. The importance of emissions trading is best highlighted by comparing the world average costs of a scenario with no trading with that of a full-trading scenario (Figure 6). The average cost saving for the world (in the case of an equal per capita emission rule) reaches 80 per cent for the more moderate options[14] and 60 per cent for the most ambitious abatement. Apart for the most ambitious abatement program, emissions trading accounts for a larger cost differentiation than the level of the abatement effort.

35. The role of permits trading can also be expressed from the perspective of environmental efficiency. For instance, according with the Figure 6, a fairly ambitious stabilisation below 550 ppmv (« low risk » option) using permits trading should not cost more - and even less - than the « Kyoto for ever » scenario without trading (see Figure 6) which, as mentioned above, has almost no impact on carbon concentration. Thus, the « flexibility mechanisms » make feasible to achieve more ambitious stabilisation objectives.

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sense, it overestimates the amount of transfers as it does not take into account the multiplier effects of these transfers. On the other hand, transfers are underestimated to the extent that they are calculated relative to the baseline scenario so that they do not offset the incentive of free riding which would occur from the positive spill-over effects from staying outside the coalition.

[10] Assuming a discount rate of 3 per cent per year.

[11] Thus, this scenario assumes that the total emission target decided in Kyoto is spread over the entire world and that non-Annex 1 countries can sell permits to Annex 1 countries to the extent of their emissions in the BaU scenario.

[12] It must be kept in mind that there are average percentages discounted over a long period of time (40 years). Thus, undiscounted percentage losses at the terminal year are much higher : above 2 per cent per year for the most ambitious option.

[13] Slight differences are related to the dynamic nature of the model.

[14] The existence of some hot air partly explains the high rates of cost-saving in the 740 ppmv and "high risk" 550 ppmv scenarios. The situation from which the extension of the Protocol takes place is also different. In the no-trade situation, increasing participation of non-Annex 1 countries starts from 2010 onwards assuming that the abatements of Annex 1 are met without emissions trading. In the full-trade scenario, on contrary, ,up to 2010, the Protocol is implemented assuming full world-wide emissions trading. Thus, gains from permits trading incorporate the gains achieved by trading the total reduction decided in Kyoto world-wide (therefore, assuming an "unrestricted" CDM).

4.2. The choice of the burden-sharing rule matters if the use of the 'flexibility mechanisms' is restricted.

36. However, there are grounds to consider that the « flexibility mechanisms » will not achieve complete equalisation of marginal costs across countries, even if they are successfully implemented. In that sense, it is justified to look to the opposite assumption of no emission trading as a benchmark situation. The Figure 7 reports the world average costs of the alternative burden-sharing rules assuming no permits trading. It makes obvious that, under this assumption, the choice of the burden-sharing rule becomes critical. In all three abatement options, the rule based on ability to pay looks the most costly one. Conversely, the "grandfathering" allocation appears as the less costly option. The rule implying an equal per capita emissions target also generates rather high costs, the level of which comes closer to the «ability to pay» rule.

37. Therefore, when departing from the assumption of no restriction and/or rigidities in emission trading, an important element in determining the cost of world-wide GHGs abatement is the choice of the burden-sharing rule. Here again, this can be interpreted in terms of environmental effectiveness: for instance, for a given level of rigidity, a "high risk"550 ppmv stabilisation based on a "grandfathering" rule would generate a much larger environmental benefit than the "Kyoto for ever" option for about the same or an even lower aggregate economic cost (see Figure 7).

38. Cost differences among rules can be explained by the distribution of abatements among high- and low-abatement cost countries. The Figure 8 shows the distribution of emissions reductions among three regional aggregates. The "ability to pay" rule imposes the highest burden on OECD and semi-industrialized countries while low-cost countries – China and India – contribute least. It is not surprising therefore that it appears as the most costly option in the absence of permits trading. Conversely, as it implies higher reductions in low-cost countries and a lower contribution from the OECD countries, the "grandfathering" rule comes out as the cheapest option. The rule based on an equal per capita emissions target has an intermediate rank. It is more costly than the "grandfathering" rule because it puts a higher burden on OECD countries but, on the other hand, it is less costly than the «ability to pay» rule as it implies more reductions in China and India

4.3. There is a trade-off between market-based and lump-sum transfers in achieving equity,.

39. The above results imply that the cost-saving potential from trading emissions is different depending on the burden-sharing rule. A rule which allocates more permits to low-cost countries and less permits to high-cost countries – just as the Kyoto Protocol does - generates a higher amount of emissions trading and, therefore, has a higher cost-saving potential. Conversely, allocating emissions (or rights to emit) in proportion of the marginal abatement costs should minimise the cost-saving impact of emissions trading.

40. The Figure 9 reports the average percentages of cost reduction achievable through emissions trading under the various scenarios. The "Kyoto for ever" scenario has the highest percentage of cost saving (about 90 %) which illustrates how central in the negotiation of the country-specific targets was the concern of extracting the largest possible benefit from the flexibility mechanisms. The Figure 9 also indicates that the gain from trading decrease as the magnitude of the corresponding abatement increases. This is understandable if we consider that the «backstops» technological options put a higher bound to the

marginal costs. Thus, with higher abatements, marginal abatement costs diverge less and gains from trading are proportionally less important.

41. Finally, the Figure 9 unambiguously shows that the «Ability to Pay» rule generates the highest potential cost saving through permits trading while the "grandfathering" option, the lowest potential. Thus, although the "grandfathering" rule is more cost-effective (in the sense that it makes the sharpest reductions where it is less costly to do it), it generates less emissions trading and therefore, has a lower distributive impact.

42. The possibility that some countries - in particular energy exporting economies - need to be compensated for their economic losses in order to participate to a global coalition is considered in the current negotiations. The Figure 10 illustrates these aspects by reporting the total amount of annual monetary flows involved by the alternative burden-sharing rules in the different scenarios. Two types of flows are considered: i) the flows associated with the sales of permits (referred to as "carbon flows"); and, ii) the compensatory payments made on top of permits sales in order to compensate countries which would lose relative to the BaU situation[15] (referred to as "side payments").

43. The monetary flows implied by all three stabilisation options are fairly large: they range from about 40 billion 1995 $ each year with the "740 ppmv" stabilisation option to more than 150 billion 1995 $ with the "low risk" 550 ppmv scenario. Furthermore, the size of these flows depends on the magnitude of the abatement rather than the nature of the burden-sharing rule. The permit price is clearly the major determinant, more than the trading potential. Thus more ambitious abatements will generate larger monetary flows, in line with the more than proportionate increase of the permit price and despite the fact that the trading potential is lower (see Figure 9).

44. The corollary of the above results is that there is a trade-off between market-based carbon flows related to permits sales and compensatory side payments. Rules, which generate more permits trading – such like the "ability to pay"and the "equal per capita emissions target" – will require less accompanying side payments. Conversely, more cost-effective rules – such like the "grandfathering" one – as they generate less permits trading will require larger amount of side payments. This clearly comes out in Figure 10. Moreover, it also appears that the «Ability to Pay» rule generates higher amount of inter-country/region flows, especially for higher abatement levels.

4.4. Stabilising concentration below 550 ppmv may already be out of range if support from developing countries requires monetary compensation.

45. The Table 1 reports the economic costs for Annex 1 countries if they engage in transfer payments to compensate non-Annex 1 countries for any real income loss incurred from their participation in emissions reductions. In the scenario where concentrations are kept significantly below the 550 ppmv threshold- the low risk 550 ppmv – the Annex 1 countries could suffer an average loss up to almost 2 per cent of their real income. This is substantially higher than any available estimate of the annual loss incurred by Annex 1 countries due to the damages caused by the extent of global warming associated with the doubling of pre-industrial GHGs concentration levels.

46. For moderate abatements, the "grandfathering" rule is not significantly less costly to Annex 1 countries than the two other rules. One would expect the "grandfathering" rule to be in favour of Annex 1 countries. But this benefit is offset by the side payments if monetary compensations are part of the

15. See the footnote 8.

agreement. For higher abatements, however, the “grandfathering” rule unambiguously comes out as the less costly option.

47. Corresponding figures for non-Annex 1 countries are reported in the Table 2. They point to a rather paradoxical result: i.e. that non-Annex1 countries lose more under «Equal per capita emissions» and «Ability to Pay» rules than with ”grandfathering” which, in principle, is more demanding for non-Annex1 countries. This reflects the heterogeneity of the non-Annex 1 group of countries: in particular, the ”grandfathering” rule shifts the burden of abatement to low cost developing countries (China and India) while the two other rules require higher commitments in oil-consuming semi-industrialized countries (which have rather high marginal abatement costs).

48. The results also highlight the distributive potential of emissions trading. Under the «Ability to Pay» and «Equal per capita emissions» rules, permits trading suffices to compensate non-Annex 1 countries, at least at the aggregate level. This is not the case with the “grandfathering” rule, which requires larger amount of side payments.

5. Conclusions.

49. The current structure of the Kyoto Protocol embodies an underlying rule of participation based on the level of emissions per capita or some kind of criterion based on the «Ability to Pay. The Protocol also contains a number of explicit and implicit restrictions on the use of the “flexibility mechanisms” aimed at redistributing the initial country-specific commitments in a cost-effective way. The analysis shows that extending the Kyoto Protocol to non-Annex 1 countries while keeping this structure unchanged is likely to be a costly option. Indeed, the simulations show that, with no or restricted permits trading, the two burden-sharing rules which seem to underlie the degree of participation to the Protocol are significantly more costly than the alternative ”grandfathering” rule.

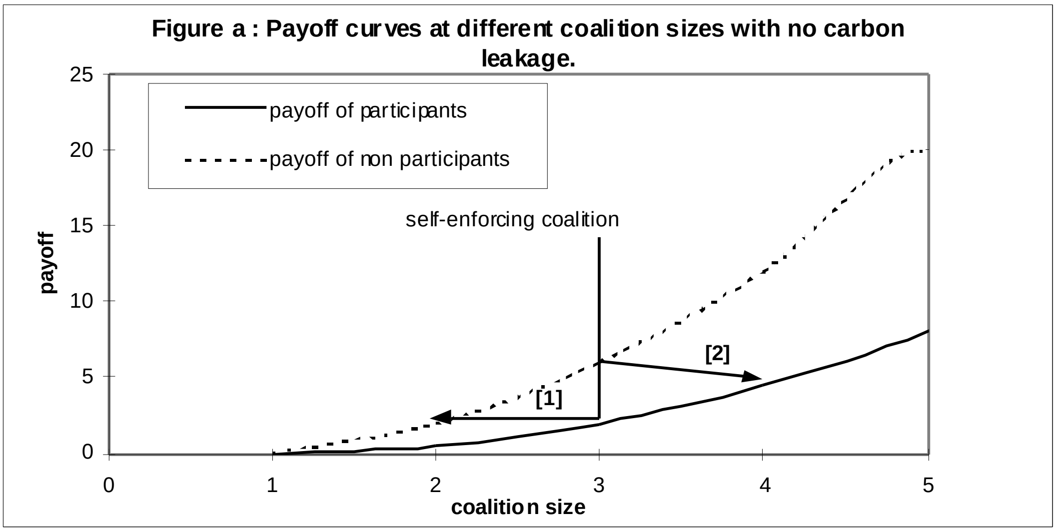
50. A corollary is that extending the Protocol to non-Annex 1 countries should require imperatively removing all restrictions on emissions trading and the CDM. However, even if all restrictions specified in the current version of the Protocol are removed, substantial transaction costs are likely to remain especially to what concerns the use of the Clean Development Mechanism. In that sense, a rule putting more emphasis on a “grandfathering” allocation of the emission rights may prove less costly than the one underlying the current version of the Protocol.

51. However, the analysis also shows that no burden-sharing rule is perfect. Indeed, the alternative «”grandfathering”» rule appears less costly but hardly acceptable by developing countries unless it is accompanied by large amount of side payments. No one government would find politically attractive the proposal of unilaterally transferring large amount of national wealth abroad. From an economic perspective also, it may be argued that market-based transfers are preferable to side payments.

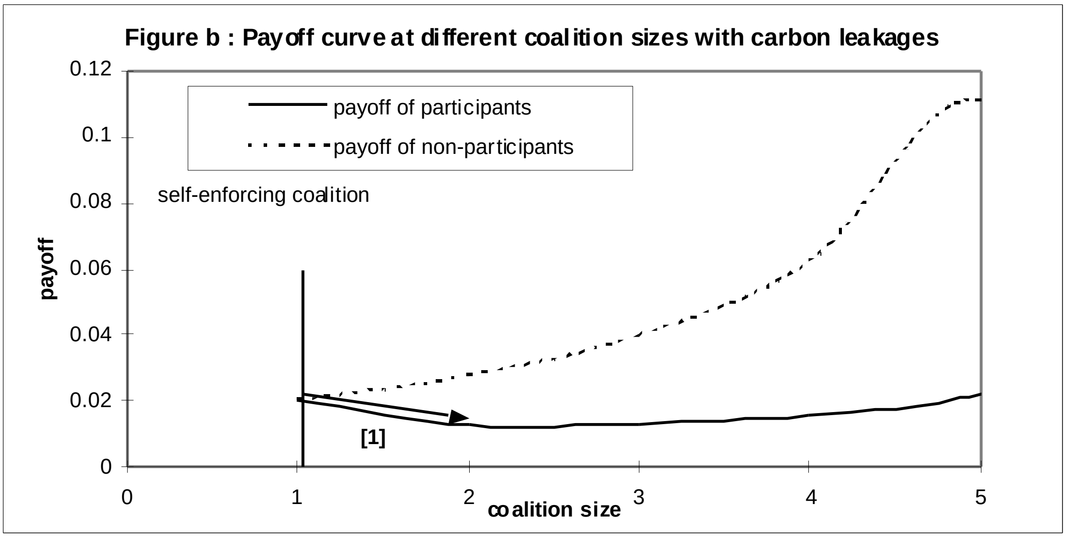
Box 1. Establishing a global agreement -- the theory

Game theory identifies the conditions for a coalition of countries taking policy action with a global environmental objective to exist and be stable: first, each participant in the coalition should gain compared with the initial situation where nobody co-operates; second, nobody should have an incentive to leave or to join the coalition. With these two conditions satisfied, the coalition is said to be "self-enforcing".

The problem of forming a self-enforcing coalition can be illustrated by comparing the net benefits of participant and non-participant countries under the assumption that all countries are symmetric (i.e. they have identical marginal abatement costs, damages and environmental preferences). Countries outside the coalition enjoy the global environmental benefit from the action undertaken by the co-operating countries without supporting any abatement costs. As a result, countries have an incentive to free-ride. This is illustrated in the following figure a where the payoff of non-participants (i.e. their net welfare gain) always exceeds that of coalition countries whatever the size of the coalition. Payoffs increase monotonically with the size of the coalition, as the environmental gains rise with the number of participants. The figure a also illustrates that there may be an equilibrium at which no country has an incentive to join the coalition (because its payoff outside the coalition is higher than the payoff it would have as a participant in an enlarged coalition) and no country has an incentive to leave the coalition (because its payoff in the coalition is higher than the payoff it would have outside a smaller coalition[1]). This equilibrium determines the size of the self-enforcing coalition. It has been demonstrated that this size is typically small (Hoel, 1991; Barrett, 1992, 1994, 1997 and Carraro and Siniscalco, 1992). Botteon and Carraro (1998) have shown that this conclusion may hold when some types of asymmetries across countries are accounted for.



[1] internal stability : no participant has incentive to leave the coalition.
[2] external stability : no non-participant has incentive to join the coalition



[1]] nobody has any incentive to form a coalition; the equilibrium coalition is a singleton.

In the context of climate change, an important factor in determining the size of a self-enforcing coalition is the magnitude of carbon leakages. High carbon leakages reduce the global environmental benefit so that coalition countries would pay the abatement costs without receiving the corresponding benefits, thus reducing the incentive to form a coalition (with high leakage the coalition payoff may no longer be monotonically increasing as illustrated in Figure b). At the same time, non-participating countries get a higher payoff associated with the economic benefits of carbon leakages (lower energy prices, improved competitiveness of energy-intensive industries). Under these conditions, the size of the self-enforcing coalition is reduced or there may even be no incentive at all to form any coalition (see, for instance, Carraro and Moriconi, 1998). Here again, this conclusion may remain valid when countries are not identical[2] (Botteon and Carraro, 1998).

Action to reduce greenhouse gas emissions may have important local, ancillary benefits. These benefits will not accrue to free-riders and the diminished incentives for free-riding will tend to increase the size of the self-enforcing coalition. Whether in practice the effects from leakage or the effects from local ancillary benefits will dominate is unclear.

The size of an environmental coalition can be expanded in a number of ways. First, a system of transfers may be designed so that no country refuses to join a coalition. However, for such an outcome to be achieved, a group of "core" countries need to be committed to co-operation (Carraro and Siniscalco, 1993; Hoel, 1994; Carraro, 1998*a*). In that sense, the resulting agreement is no longer self-enforcing. Another way to expand a coalition is by "issue linkage": it has been suggested, for instance, to link environmental negotiations to negotiations on trade liberalisation (Barrett, 1995) or on R&D co-operation (Carraro and Siniscalco, 1995; Katsoulacos, 1997). But Carraro (1998*a*) shows that, by generating an incentive to exclude some countries from the agreement, issue linkage may not necessarily be successful in achieving the environmental objective. At the same time, such a strategy may imply risks of inferior outcomes in the linkage area.

Finally, the size and stability of the coalition may be influenced by the rules of the negotiation process and the behaviour of participants. For instance, the equilibrium coalition would be larger if countries correctly conjecture the consequences of their decision to leave or to join the coalition (Carraro and Moriconi, 1998). If more than a single agreement is allowed, the equilibrium outcome is characterised by several coalitions which implies that more countries undertake abatements although the total abatement is not necessarily higher (Carraro, 1998a and 1998b). Different membership rules leads to coalitions with different sizes. For instance, the equilibrium coalition would be larger if membership is subject to an unanimity rule -- i.e. that no entry or exit is allowed without unanimous consent of coalition members (Carraro and Moriconi, 1998). Here again, achieving the grand coalition (i.e. a coalition grouping all countries) would require some form of commitment.

To the extent that the Kyoto Protocol corresponds to the small self-enforcing coalition predicted by theoretical models, it has the implication that extending the Protocol could require additional provisions, covering, for instance, financial transfers and some form of commitment. The current process implies a complete re-negotiation of the agreement at the end of each budget period, including new membership and targets for emissions reductions, which, according to the game theoretic models, may imply insufficient commitment to expand the current coalition.

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1. And assuming that its decision to leave the coalition does not influence the remaining participants in the coalition.
2. Botteon and Carraro (1998) also show that, with asymmetric countries, leakages reduce the size of the coalition when the initial coalition is small but increase the size of the coalition when the coalition is initially large.

BOX 2. TRANSLATING PAST CO_2 EMISSIONS INTO FUTURE CONCENTRATION

The impact on concentrations of policies to reduce emissions is usually assessed by using reduced-form "response functions". These functions typically expresses how a change in emissions in time t would deviate the future time path of concentration relative to the baseline. The baseline itself is obtained by using complex models with full specifications of the various components of the carbon cycle. Establishing a baseline for concentration and assessing how policies would modify this baseline is subject to many uncertainties. First, many aspects of the carbon cycle are not well known, as for instance the fertilisation effect, and, more importantly, it is not known how this cycle would behave at concentration levels much above those that were attained in the past[16]. Second, carbon cycles have a very long term dynamic (several hundred years) which requires projections of economic growth over a period far too long to imagine the technological options that might be developed. Thus this exercise has no predictive value; its aim is only to highlight the dynamics at work.

6. Defining a baseline projection of emissions

The purpose of this analysis is to calculate the level at which emissions must be ultimately brought down in order to stabilize the carbon concentration in the atmosphere at a given level. A preliminary step is to define a baseline projections of emissions and concentration over a period of 200 years. This projection covers CO_2 emissions from both fuel combustion and land-uses changes. It is based on the emission time path projected by the GREEN model up to 2050. This time path is extended for the period from 2050 to 2200 by using the following set of simplified assumptions:

- the population in Annex I countries remains stable after 2050 while, in non-Annex I countries, projections of population are linear extrapolations of the trends over the period 2030-50. As a result, the world population grows by 0.8 per cent annually on average from 2010 to 2050 and by 0.4 per cent per hereafter.

- the projection of the GDP per capita in the non-Annex I is based on the assumption of a partial catch-up of productivity levels. Following this assumption, the ratio of average GDP per capita in non-Annex I countries to Annex I countries is close to 50 per cent in 2200 (against 6 per cent in 1990). In the same time, Annex I GDP per capita converge to an average level as projected by *linear* extrapolation of the trends over the period 2030-50.

- emissions per capita are projected by using a log-linear relationship between emissions per capita and GDP per capita which is fitted on data from the BaU scenario from the GREEN model for the period 1985 to 2050. As Figure 1 shows, this relationship implies that emissions per capita grows less than proportionally with the level of the GDP per capita. Emissions per capita are assumed to converge to their values predicted by the log-linear

16. A recent study by Cao and Wooodward (1998) however suggests that the fertilisation effect would level off at a CO_2 concentration of 450 ppmv. If true, this would imply almost no fertilisation effect for the range of concentrations which are considered in the following scenarios.

relationship by 2200 which, for some Annex I countries (for instance the United States and the CIS), implies a long-term decline of the emissions per capita ratio.

– following these assumptions, world emissions are projected to grow 0.7 per cent per year during the period 2050 to 2200 (compared with 2.4 per cent per year from 2010 to 2050, as projected by the GREEN model). Emissions of Annex I countries would culminate at 8 gigatonnes per year in 2050 and decline slightly hereafter (by 0.2 per cent per year). Thus the growth of the CO_2 emissions over the very long term would originate entirely from non-Annex I countries (mainly the Rest of the World (ROW), the Energy Exporters (EEX) and India). The implication is that, by this time, the weight of Annex I emissions in world emissions would become rather small.

A reduced-form model of the carbon cycle

Any simple representation of the carbon cycle contains at least a function which specifies the proportion of a given carbon emissions as a function declining over time following a roughly exponential path (called a "response function"). There exists alternative specifications[17] of response functions, the one used here being the Wigley's model[18] in which the CO_2 remaining in the atmosphere at time t is a linear function (a proportion) of the amount of CO_2 emitted in previous years. Thus, atmospheric concentration in time t (C_t) is a function of the weighted sum of past emissions (E_u). The weighting factor -- R_{t-u} -- characterises the response function; it expresses the percentage of CO_2 emitted in time u which is still in the atmosphere in time t, i.e. t-u years after it has been emitted. In principle, its value is equal to unity for the previous year's emissions and declines more or less exponentially for earlier years' emissions. The equation can be written as follows:

$$\textbf{[1]} \quad C_t = C_{t0} + 0.471 \sum_{u=t0}^{t-1} R_{t-u} \cdot E_u$$

with t0 being the reference year starting from which concentration are calculated (in practice, 1765 considered as the benchmark year for defining the pre-industrial level of concentration). The factor 0.471 converts gigatonnes of CO_2 into ppmv.

Weights of this response function have been chosen within the range of magnitude quoted in the literature on carbon accumulation (see Ha-Duong, Grubb and Hourcade, 1997)[19]. The equation is calibrated such as to reproduce the level of concentration observed in 1990 (354 ppmv).

Steady state stabilisation versus local maxima

Any single stabilisation target can be reached by a variety of alternative emissions timepaths. The choice is between taking early measures in order to spread the burden of the adjustment over a longer

17. For instance, the Bern model (Siegenthaler and Joos, 1992) or the model of Jain (Jain *et al.*, 1995).

18. Wigley, 1993.

19. We use a model that Minh Ha-Duong from the CIRED has developed on Mathematica. In this model, the weighting factors describing the lifetime of CO_2 in the atmosphere range from 1 for the CO_2 emitted today to 0.247 for the CO_2 emitted 535 years ago.

period of time or, alternatively, delaying the adjustment in the hope that it can be made at lower economic costs later on. Assessments based on models show that a delayed action is likely to be less costly. However, the choice of a delaying action is restricted by technical feasibility and inertia of energy systems. A related issue is to determine the level of emissions which corresponds to stable concentration in the long run.

Figures 2a to 2d aims at highlighting the long-term properties of the carbon cycle dynamic. They simulate different concentration timepaths corresponding to reductions to given minimum levels of emissions spread over different time spans. For instance, in Figure 6a, the trajectory 10-30/4 corresponds to a reduction of world emissions down to 4 gigatonnes of carbon per year (compared with 8 gigatonnes in 1995) spread over the period from 2010 to 2030, with emissions remaining constant at this 4 gigatonnes level for ever after 2030. The timepath 10-30/0 simulates the complete elimination of any CO_2 emissions over the same period. A number of findings come from these diagrams:

- Only a few trajectories lead to effective stabilisation of the CO_2 concentration over the long run. These trajectories (in bold in Figures 6a to 6d) correspond to an equilibrium in which emissions match the amount of carbon which is sequestered from the atmosphere in each year. The level of these equilibrium emissions is very low: it amounts to 0.5 gigatonnes of carbon per year if the stabilisation starts in 2010 (10-30/0.5 in Figure 2a, 10-60/0.5 in Figure 2b) and to 1 gigatonne of carbon per year roughly if the stabilisation starts in 2050 (50-70/1 in Figure 6c, 50-100/1 in Figure 2d). Thus, effectively stabilising the CO_2 concentration requires bringing emissions down to very low levels compared with the current ones[20].

- Trajectories with long-term minimum emissions above these equilibrium levels do not effectively leads to stabilise concentration in the sense that, in the long run, concentrations are still increasing. However, some of these trajectories exhibit a local maximum after which concentrations temporary decline and start rising again hereafter (for instance, 10-30/1 in Figure 2a). Emissions reductions corresponding to these trajectories are, at the most, seen as delaying the rise of concentration rather than stabilising them.

- Delaying reductions increases the equilibrium level of concentration (i.e. the level at which the concentration does not rise any more). Concentration could be stabilised at 380 ppmv if reductions start in 2010 (10-30/.5 in Figure 2a) while the corresponding level is 513 ppmv if there is no reduction before 2050 (50-70/1).

- Spreading the reductions over a large time span increases the equilibrium level of concentration as well as their local maximum, increasing the risk of irreversible climate damage (compare, for instance, 50-100/1 in Figure 2d with 50-70/1 in Figure 2c).

- Non-Annex I countries may effectively wait until 2050 before imposing any reduction as long as world emissions can be cut down to less than 1 gigaton per year over a more or less long period of time. A similar conclusion is reported by Wigley (1997).

- A strategy of early cuts down to emissions above their long-term equilibrium levels may do less for stabilising the climate than a strategy of late but very drastic cuts. This can be seen by comparing the trajectory 10-30/4 with the trajectory 50-70/1. However, the former would

20. A result which is confirmed by other studies using different models of the carbon cycle, see Enting, Wigley and Heimann, 1994.

maintain concentration at lower levels on average over the period considered although still on a rising trend. Since the former strategy is likely to be more costly, the choice between the two strategies ultimately depends of the degree of uncertainty and risk aversion.

Figure 1. Relationship between emissions per capita and GDP per capita in GREEN BaU scenario

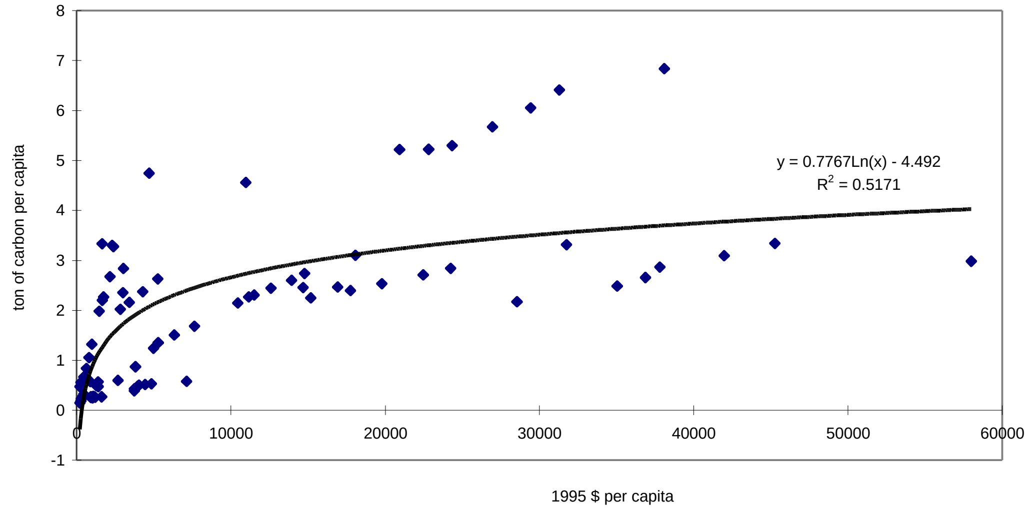
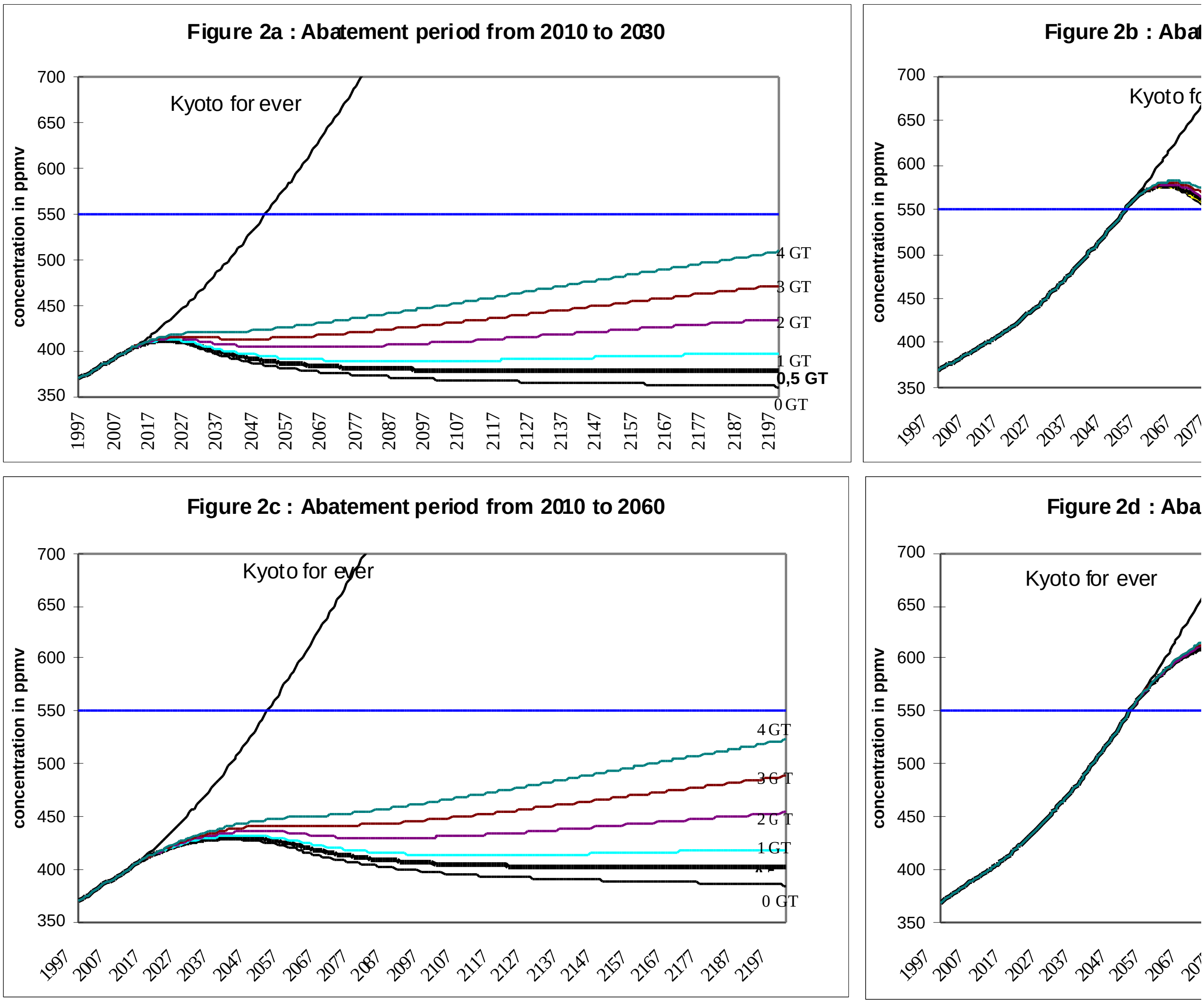


Figure 2 : Alternative pathways to stabilie CO2 concentration.



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