Equitable Provision of Long-Term Public GoodsThe role of Negotiation Mandates

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First draft: January 2001
This version: June 17, 2003

Abstract

We examine the international distribution of expenditures for the provision of a global, long-term and uncertain public goods from the point of view of a benevolent planner. Even assuming a "no-redistribution" constraint, first period expenditures are in general progressive with income, and independent both from total level of action, and from future distribution of damages. However, in status-quo mandates—where current negotiating powers shape both present and future allocation—future distributions of efforts are very unequal, and agreement, if any, is at high risk of instability. An adaptative mandate proves necessary to provide an acceptable solution.

JEL Classification: D63, H41, Q25

1. Introduction

Providing transnational, long-term and uncertain public goods such as the ozone layer, biodiversity or climate confronts inter and intra generational distributional issues simultaneously. The economic literature addressed this issue (Sandler, 2001), in particular through extending the Bowen-Lindhal-Samuelson (BLS) conditions to the intergenerational case (Sandler and Smith, 1976). However, the history of climate policies shows that negotiations still rely on rhetorics based on pure ethical intuitions such as common but differentiated responsibilities, *per capita* distribution of emission rights (Agarwal and Narain, 1991), or the grandfathering scheme. Two actors of this negotiation from both sides of the Atlantic (Bodansky 2001, Hourcade 2002) show how the reluctance of putting some economic insights in the discussion made it difficult to control the political vagaries of the process and to find a ground to reconcile opposite views.

Economists may be in part responsible for this lack of influence because of their reflex to keep ethics separated from economics. This paper builds on follow the opposite advice that *"there is something in the methods standardly used in economics, related inter alia with its engineering aspect, that can be of use to modern ethics as well"* (A. Sen 1987, p.9). To do so, using climate as an empirical case, it interprets the benevolent planner metaphor as capturing the behavior of the chairman of a Conference of the Parties[1] presenting a take or leave proposal in the final hours of the negotiation (Grubb et *al.*, 1999).

Using a two period framework, we define four mandates that can be given to the planner; these mandates combine assumptions about:

- diplomatic attitudes: we distinguish a *status-quo* approach, whereby current balances of power are used to shape long-term policy, and an *adaptative* approach whereby evolutions in the distribution of economic income and power are recognized;

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[1] The COP is the negotiating body of the U.N. Framework Convention on Climate Change (UNFCCC).

- visions of intergenerational solidarity in the face of climate risks: we distinguish between *dynastic solidarity*, whereby Parties are concerned by the welfare of their future citizens only, and *universal solidarity*, whereby Parties consider the welfare of all future individuals, regardless of where they live.

These mandates are analyzed under a no redistribution constraint because countries are not likely to let climate policies—or any other international treaty of that sort—be the occasion of large-scale wealth redistribution across nations. We first focus on the burden sharing principles which emerge from these mandates, and on their political viability. We then examine their implications for the level of provision of the public good. At each step, we analyze the specific role of uncertainty. Finally, we derive conclusions for the future of regimes apt to manage global and future public goods in an unequal word.

2. A Generic Model with Three Alternative Programs

Let us start from a generic model similar to the one developed by Sandler and Smith (1976). The world is divided in N countries, and there are two periods, present and future, the latter indexed by superscript f. At first period, the representative individual[2] of the l_i inhabitants of country i allocates his revenue y_i between c_i the consumption of a composite private good chosen as numeraire, and a_i his abatement expenses.

$$y_i = c_i + a_i \tag{1}$$

Let x (resp. x^f) be the amount of greenhouse gases emissions (GHGs) abated worldwide compared to business-as-usual. We use $x+x^f$ as an index of the climate change stock externality,[3] and denote $d_i(x+x^f)$ the *per capita* level of damages incurred in country i at second period. Since $x+x^f$ aggregates avoided tons of GHGs, functions $d_i(.)$ are decreasing. Thus, second period budget equations are as follows.

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[2] We will not address the internal distribution of revenue in each country.
[3] This (inversed) index is a simplification of the dynamics of GHG accumulation in the atmosphere, but it suffices in capturing the stock externality character of climate change.

$$y_i^f - d_i(x+x^f) = c_i^f + a_i^f \tag{2}$$

We assume that abatement expenses are used efficiently and denote $C(x)$ (resp. $C^f(x^f)$) the worldwide abatement cost function, and the total level of abatement at each period is thus given by:[4]

$$\sum_i l_i\, a_i = C(x) \qquad \sum_i l_i^f\, a_i^f = C^f(x^f) \tag{3}$$

At the beginning of the first period, the planner/chairman of the COP is charged with proposing an abatement level for each country at both periods. This one-shot model is arguably at odds with the sequential nature of the real climate regime, where targets are set for five-year periods only. But, climate change being a stock externality, the planner cannot but make assumptions about future action when computing present one; second period abatements can thus be interpreted as plans which may, or may not, be carried out (section 4).

To draft a proposal with reasonable chances of being accepted, the planner maximizes a collective welfare function $W = \sum l_i\ \alpha_i\ U_i(.)$, which is a weighted sum of the representative individuals' utilities, and he specifies W and selects weights α_i in function of the mandate he receives from the Parties. If we assume, despite its controversial character from an ethical point of view,[5] that wealthiest Parties impose a no-redistribution constraint, then this collective welfare function must meet the following two technical conditions.

- national contributions a_i and a_i^f must be non negative, as no Party will accept to abate more in order to endow another Party with

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[4] Let x_i be the country abatement levels, and $C_i(x_i)$ the national abatement cost functions. Then $C(x) = \text{Min}\ \{\sum_i C_i(x_i)\ |\ \sum_i x_i = x\}$. This can be interpreted as a carbon fund provisioned by all countries and which reduces emissions where it is cheapest to do so.

[5] See Azar (1999, p.254): "The global welfare function is a normative, not an empirical question, and few would contest that the world would actually be a much better place if the huge differences income were reduced. A situation where the richest billion people live in abundance, and the poorest billion suffer from chronicle hunger, can by no reasonable standards be considered a global welfare maximum."

emissions rights higher than its baseline prior to any carbon trading[6]. This condition is seemingly trivial but we will show that it plays a role at the second period equilibrium.

   - Second, the weights of the representative individuals must be such that the initial distribution of wealth (y_i) is welfare maximizing.[7] Negishi (1960) tells us that these weights are unique—up to a scale factor—and equal to the inverse of the marginal utility of initial revenues. If utility functions are logarithmic and if first and second period consumption are separable, these weights are proportional to per capita revenues.[8]

   However, the set of welfare functions which meet these restrictions is still rather large because there are various ways of interpreting the no redistribution imperative at the second period and various attitudes vis-à-vis climate damages.

   With regard to the no redistribution constraint, modelers (e.g., Nordhaus and Yang, 1996) often consider that it applies separately at each period. The Negishi weights are thus made time-varying so that the projected distribution of income (y_i^f) is welfare maximizing at second period. But, by doing so, one makes a strong assumption about the political economy of the negotiation, namely that Parties agree to ask the planner to anticipate changes in income distribution. In other words, this presupposes a consensus on the legitimacy or the ineluctability of changes in economic balances, which contradicts diplomatic traditions where negotiating powers are governed by prevailing balances of power.

   It is not implausible that Machiavelli's qualification of States as "cold monsters" will remain valid in the 21st century. The richest

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[6] The excess quota allocated to Russia and Ukraine by the Kyoto Protocol is obviously a pure tactical concession. In a milder approach no Party shall benefit from climate policy as a whole; thus the sum of contribution and damages shall be non negative ($a_i^f + d_i^f > 0$).

[7] To avoid any misunderstanding, let us make clear that this technical trick capturing political constraints does not imply a substantive value judgment on the equity of current state of the world.

[8] Were these weights all set to 1, total income should be redistributed so as to achieve equal per capita revenue.

countries may well not accept the ineluctable decline of their share in world's wealth, or may at least tend to use their current superiority to slow down this decline. They may then be tempted by a status-quo mandate, whereby they force the planner to calibrate the collective welfare function at both periods based on current income distribution.

Regarding the interplay between the assessment of climate damages and intergenerational equity, two polar attitudes are again possible. The first derives from the observation that negotiating team, defending national interests and speaking on behalf of both its present and unborn fellow citizens, tends to follow a dynastic solidarity conduct and primarily considers the damages falling on their own country. A polar option, expressed by many NGOs, is that decision-makers should adopt a universal solidarity ethic, and should be concerned by the welfare of all future individuals, regardless of where they live, and of where damages fall.[9] This alternative can be translated analytically by making second period utilities dependent, or not, on damages in other countries.

Four possible programs can be derived by combining these two sets of hypothesis. If we denote α_i and β_i the first and second period weights respectively,[10] and φ the utility discount factor,[11] they are:[12]

- "Dynastic solidarity" and "status-quo" mandate:

$$W = \sum_i l_i \, \alpha_i \, U_i(c_i) + \varphi \sum_i l_i^f \, \alpha_i \, U_i^f(c_i^f) \tag{4}$$

$$\alpha_i = \frac{\alpha}{U_i'(y_i)} \qquad \qquad \text{with } \alpha = \left(\sum_i \frac{l_i}{U_i'(y_i)} \right)^{-1} \tag{5}$$

- "Dynastic solidarity" and "anticipative" mandate

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[9] We will discuss later the ethical rationale and political likelihood of this mandate. For the time being, we treat it as a pure logical possibility.

[10] We assume that the sum of weights over all country is equal to one.

[11] We assume here that all Parties have the same pure time preference. This still allows for differentiated discount rates across countries, as utility functions and growth rates might differ.

[12] Present and future consumptions are always assumed separable.

$$W = \sum_i l_i \, \alpha_i \, U_i(c_i) + \varphi \sum_i l_i^f \, \beta_i \, U_i^f(c_i^f) \qquad (6)$$

$$\alpha_i = \frac{\alpha}{U_i'(y_i)} \qquad\qquad \text{with } \alpha = \left(\sum_i \frac{l_i}{U_i'(y_i)} \right)^{-1} \qquad (7)$$

$$\beta_i = \frac{\beta}{U_i^f(y_i^f)} \qquad\qquad \text{with } \beta = \left(\sum_i \frac{l_i^f}{U_i^{f'}(y_i^f)} \right)^{-1} \qquad (8)$$

  - "Universal solidarity" mandates are obtained by substituting U_i^f (c_i^f, d_1^f,…,d_{i-1}^f,d_{i+1}^f,…,d_N^f) to $U_i^f(c_i^f)$ in equations (4) and (6) respectively. The damages falling on other countries, in addition to those falling on the country i are thus included in the calculation of c_i^f.

3. Burden Sharing at First Period: Towards an Easy Rule of Thumb?

In all four mandates, solving the planner's program yields the same result at first period: abatement expenses should be allocated so as to equate after abatement weighted marginal utilities of consumption across countries (see Appendix 1 for full derivation of the result) which expresses the BLS condition in the context of our model.

$$\alpha_1 \, U_1'(y_1 - a_1) = \ldots = \alpha_N \, U_N'(y_N - a_N) \qquad (9)$$

Since, by virtue of the no redistribution constraint, before abatement weighted marginal utilities are also equal, the optimal distribution of abatement costs decreases the weighted marginal utilities by the same amount.

$$\alpha_1 \, U_1'(y_1) - \alpha_1 \, U_1'(y_1 - a_1) = \ldots = \alpha_N \, U_N'(y_N) - \alpha_N \, U_N'(y_N - a_N) \qquad (10)$$

Figure 1 provides a geometric illustration of this result, picturing two regions differing only in income. Since preferences are the same, the poor region has a higher marginal utility of consumption (B) than the rich one (A). To comply with the no redistribution constraint, the planner chooses α_{poor} (normalizing α_{rich} to 1) such that the weighted marginal utilities of consumption in both regions are equal in the no-policy scenario. The weighted marginal utility of the poor region is

thus C instead of B. To preserve this equality in the post abatement equilibrium, it suffices to find the horizontal line intersecting with both the marginal utility function of the rich (continuous line) and the weighted marginal utility function of the poor (dotted line), such that $a_{poor}+a_{rich}$ is equal to the total desired level of abatement.

Contribution a_{poor} is lower than a_{rich} if the slope of the weighted marginal utility function is steeper at point C than the slope of the marginal utility function is at point A. This occurs when the ratio of the slope of the non weighted utility function in B and A is higher than the ratio of marginal utilities between B and A. An analytic condition can be easily derived when contributions a_i are all assumed to remain small compared with initial revenues y_i. In that case, equation (10) can be approximated by:

$$-\frac{U''}{U'}(y_{poor})\ a_{poor} \approx -\frac{U''}{U'}(y_{rich})\ a_{rich} \tag{11}$$

In other words, for all $y_{poor} < y_{rich}$

$$a_{poor} < a_{rich} \quad \text{if and only if} \quad -\frac{U''}{U'}(y_{poor}) > -\frac{U''}{U'}(y_{rich}) \tag{12}$$

The latter condition holds (see Appendix 3) for a large class of utility functions, in particular with logarithmic utility functions $U = \ln(c)$, and exponential utility functions $U = c^a$ (0<a<1) since $-\frac{U''}{U'} = \frac{1}{c}$. With such functions, optimal abatement expenditures are proportional to per capita revenues: if the average European is 46 times richer than the average Indian,[13] then each European should contribute 46 times more to climate mitigation, in absolute terms, than the average Indian. However, by construction of the weights, their utility loss is identical.

This has four policy implications for the first period. First, all countries should contribute to climate mitigation. Second contributions are in general progressive with and proportional to income. Interestingly, while grounded on conservative assumptions regarding income distribution, this outcome might be consistent with

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[13] Based on 2000 Gross National Income, as reported in World Bank, 2002.

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the "common but differentiated responsibilities" principle of the UNFCCC. Third, this burden sharing rule—at least as long as contributions remain small with regard to initial revenues—is independent from both the optimal level of public good $(x+x^f)$, and from the first period emissions level x. Last, it is entirely independent from the distribution of the impacts of climate change, and thus robust to their uncertainty (see Appendix 2) since it depends only on first-period utilities and income level.

In sum, regardless of the mandate, intra-generational equity at first period can be addressed using a simple "rule of thumb" based on observable parameters and can be separated from the controversies about intergenerational distribution and the abatement targets.

4. Burden Sharing at the Second Period: when Mandate Matters

We now turn on to burden sharing at second period. The core of this section is analytical, but numerical exercises with two regions, developed and developing, illustrate our findings and provide the orders of magnitude of the parameters at stake.

4.1. The Status-Quo – Dynastic Mandate at Risk of Instability

Under the status-quo – dynastic mandate, burden sharing at second period is governed, like in the first, by the equalization of weighted marginal utilities of consumption:

$$\alpha_1 \, U_1^{f\,'} \, (y_1^f - d_1^f(x+x^f) - a_1^f) = \ldots = \alpha_N \, U_N^{f\,'} \, (y_N^f - d_N^f(x+x^f) - a_N^f) \tag{13}$$

The resulting distribution of abatement costs, however, is dramatically different. This is in part due to the fact that both damages and abatement expenses enter in (13). But the main reason is that, since the α_i are calibrated on first period incomes, the vector y_i^f has no reason to be welfare maximizing. And in most instances it is not.

Figure 2 shows what happens in this case (assuming that damages remain small compared to revenues). If before abatement weighted

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marginal utilities differ, then the optimal plan consists in charging all abatement expenditures to the country with the lowest weighted marginal utility. The planner shall do so until abatement costs raise the weighted marginal utility of this country enough to equate the level of the second in rank, at which point both are charged; and so on until all abatement expenditures are covered.

If utility functions U_i and U_i^f are identical, the country with the lowest weighted marginal utility before abatement at second period is the poorest country (see Appendix 4). Since developing countries are projected to experience higher growth rates than developed economies in the coming decades (Nakićenović and Swart, 2000, World Bank, 2003), this leads to a paradoxical outcome; let us assume, for instance, that the poor region grow by 3.0% annually over the next decade, and the rich region by 2.5%. In this scenario, the former would be about 5% richer in 2010 than it would be under a 2.5% growth rate. This "extra growth" represents 1% of the world gross product in 2010; then all the effort should fall on the poor region as long as annualized abatement costs over this period is lower than that amount.

This result cannot be reversed when accounting for climate damages, even though they are expected to be higher in the developing world (McCarthy et *al.*, 2001). If we assume—fairly conservatively—that per capita GDP growth of the developing world is half a point higher than this of developed countries during the next 50 years, then per capita GDP in 2050 is 27% higher in the developing world than it would have been had both rates been equal. Regional damages apt to rip off this "overgrowth" are beyond the most pessimistic expectations about damages, small Island-States and Sub Saharan Africa excepted.

In sum, under this mandate, large countries such as China, India, Brazil, or Mexico would be called to pay most of the abatement expenditures at second period, even if they are expected to suffer from higher damages than the developed world. Factoring uncertainty in complicates the problem but does not change its logic.

This result looks so unacceptable by developing countries that one cannot but question the policy relevance of the underlying model. Its main weakness is that it features only two periods; even though our numerical examples demonstrate that introducing shorter time periods would not fundamentally change the substance of the issue, one could argue that, in the real decision-making process, Parties agree only on the first period expenses, and that the second period distribution plan can be renegotiated.

This is true; however our result points out the outcome of a situation in which the structure of the first period decision has long-term impacts. Examples abound of long-lasting arrangements built on relative bargaining powers which have dramatically changed since then. The composition of the U.N. Security Council and the voting system within the U.S. are two outstanding examples. In the climate policy context, limits to renegotiating allocation rules come from the very cornerstone of the Kyoto regime, that is an international carbon trading system. Its dynamic efficiency would indeed be undermined were the entry of new countries not controlled by predefined quota allocation rules, and were some degree of certainty not given to governments and private agents over future levels of their carbon constraint. Changing the rules too drastically, or too often, might lead agents to refrain from using emissions trading (OECD, 1993).

Moreover, an interpretation of the status-quo – dynastic mandate is that it expands the rationale of the grandfathering principle to future generations. Indirectly, equation (13) comes to endowing the future inhabitants of the rich countries with emissions rights in part based on those acquired by their predecessors. Viewed in that light, the no redistribution constraint comes to repeated grandfathering; it is consistent with the claim that "the U.S. lifestyle is not negotiable."[14]

At first period, grandfathering is legitimated by the fact that vested interests need to be compensated for the modification of the social contract from a situation without to a situation with carbon constraint.

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[14] Even though this is a quote from a former U.S. President, it is fair to note that it would probably be endorsed in many quarters of the developed world.

This ground is not valid in the long-run any longer, which explains the repeated warning by the G77 and China that *"there would be no agreement on carbon trading until the question of emissions rights and entitlements is addressed equitably."*[15]

Under the status-quo – dynastic mandate, two main outcomes are thus possible: either the chairman's proposal is immediately rejected by the fastest growing countries or it is accepted at first period, but generates tensions at the second and strong incentives to defect.

4.2. Winner-Losers Dilemma in the Adaptative – Dynastic Mandate

Under an adaptative – dynastic mandate, burden sharing at second period is again governed by the equalization of weighted marginal abatement utilities.

$$\beta_1 \, U_1^{f\,'} \, (y_1^f - d_1^f(x+x^f) - a_1^f) = \ldots = \beta_N \, U_N^{f\,'} \, (y_N^f - d_N^f(x+x^f) - a_N^f) \tag{14}$$

But weights β_i now reflect the baseline distribution of wealth at second period, and "before climate" weighted marginal utilities are thus equal. We recover the results obtained in section 3, but they now apply to the total of abatement expenditures plus damages: with logarithmic functions, each country should entail a climate change bill in proportion to its *per capita* GDP.

Hence, abatement expenditures depend not only on the before abatement distribution of wealth, but also on the distribution of residual climate change damages. Let us illustrate with developed (N) and developing region (S). N and S, we assume, share the same logarithmic utility functions, but their first period per capita revenue differ by a factor 23. Higher per capita GDP growth in S from first to second period (3% vs. 2.5%), reduces this range from 1 to 18 in 2050. But in that period, the population of S has increased by 40% while the population of N has remained constant. Abatement costs are slightly

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[15] UNFCCC document SB/1998/MISC.1/Add.3/Rev.1 Preparatory work for the fourth session of the Conference of the Parties on the items listed in decision 1/CP.3, paragraph 5, Indonesia (on behalf of the Group of 77 and China).

higher in N than in S. Last, marginal damages are assumed quadratic with net emissions, but we test several assumptions on the share of second-period revenue that full damages (without abatement) would cause (see Appendix 5 for details).

In scenario a (see Table 1) damages without any abatement represent 5% of baseline revenues in both regions. Abatement expenditures are then allocated proportionally to per capita revenue. In scenario b, residual damages are 6% of the GDP/cap in S and 4% in N. Country N is then demanded to devote to abatement a higher share of its revenue than S so that the total climate bill (once residual damages are added) is the same in both countries. In scenario c, S is so impacted that it should not pay anything for abatement. In scenario d, damages are so high in S, that even with zero abatement expenditures, S still support a higher climate bill than N. The non-redistribution constraint $a_{north}^{f} \geq 0$ is binding, preventing the planner from transferring additional money from N to S to compensate for the extra damages.

In the latter situation, which is far from implausible for Sub-Saharan Africa or small Island-States, the no redistribution constraint is put to a serious test. Direct compensations for excess damages can only be paid if Parties make a more lenient interpretation whereby it applies to the sum of damages and abatement expenditures.

More generally, the main difficulty of this mandate stems from the very fact that damages will remain difficult to observe, quantify and compare across countries. Projections of average increase of temperature by global circulation models have indeed a higher degree of confidence than projections at a local scale, and uncertainty grows by orders of magnitude when translating local physical impacts to economic damages (McCarthy et *al.*, 2001): Western Europe may experience either a 2°C warming or a several degrees cooling depending upon the evolution of the North-Atlantic thermohaline circulation; Russia can be counted amongst the winners of global warming, unless the melting of the permafrost or the difficult adaptation of vegetation prove to be dramatic.

As demonstrated by Table n°1, only small divergences in climate damages significantly alter the allocation of abatement expenditures. Thus there are risks of non acceptance of the proposed deal (all Parties are interested in inflating their estimates in order to minimize their contribution to abatement expenditures and increasing their β) or of important the gap between expected and realized damages, which would imply important changes in the initial agreement.

4.3.   Universal Solidarity Mandates: More Robust to Uncertainty?

The "dynastic solidarity" mandates are based on the premise that Parties are primarily interested in the fate of their own descendants. This premise seems consistent with dominant diplomatic conducts.

However, alternative "universal solidarity" mandate— in which Parties consider all damages wherever they fall—can also be justified; even without adopting a *universal bonhomie* attitude. A first argument stems from Thomas Schelling's suggestion (1995) that, beyond some horizon, all individuals are indistinct[16]; a second stems from a reconsideration of pure self interests. Faced with tremendous uncertainties regarding the regional distribution of climate damages and related economic consequences, Parties might refrain from indulging themselves in the camp of the winners [17]. In addition, given the risks of propagation of local shocks—, increased economical and political instability accelerated migration —[18], Parties might consider that any important impact anywhere will ultimately affect everyone's welfare and security.[19]

A status-quo – universal solidarity mandate makes thus sense even under selfish attitude. But, in terms of allocation of abatement costs, it

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[16] The same intuition underlies the proposal of an hyperbolic discount rate.

[17] A situation analogous to the "veil of ignorance" described by John Rawls (1971).

[18] This is all the more important since adverse climate impacts may fall disproportionally on fragile regions in developing countries.

[19] The concept of solidarity can thus be understood in its etymological sense*: solidus*: compact and hence 'solid'; it means with whom we consider to be bound either for reasons of benevolence or because our interests stick together.

confronts the same difficulties as the status-quo dynastic mandate and the fact that damages are now universally accounted does not solve the second-period allocation problem, as growth differentials still exist.

In an adaptative – universal solidarity mandate, the distribution of contributions at both periods is governed by the same principle as in the adaptative – dynastic solidarity case. The main difference concerns the treatment of damages. A low impacted country will indeed consider, at least in part, damages falling on other countries. This has two main consequences. First, the total level of damages considered by parties increases compared to the dynastic case because, on top of national damages, damages abroad also matter. Second, the uncertainty on the distribution of damages—at constant global marginal damage—plays a lesser role. If a common diagnosis can be reached on the magnitude of marginal damages at global level, then uncertainty at local level matter far less as an obstacle to a burden sharing agreement.

5. Levels of Abatement

Let us now turn to the consequences of the four mandates on the provision of public goods. To do so, we will illustrate the consequences of the analytical solutions of the planner's problems (see Appendix 1 for complete derivation) with "North-South" numerical example developed above.

Abatement is governed by equations (15) and (16). They establish that the public good should be provided up to the point where its marginal cost matches the sum of the willingness to pay of all parties involved. This is identical to the BLS condition in the one period model, with the only difference that, at first period, one has to compare the marginal utility of public good consumption tomorrow, with the marginal utility of private good consumption today.

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$$C'(x) = - \varphi \sum_i l_i^f \frac{\beta_i}{\alpha_i} \frac{U_i^{f'}(y_i^f - a_i^f - d_i(x+x^f))}{U_i'(y_i - a_i)} d_i'(x+x^f)$$

$$- \varphi \sum_i l_i^f \frac{\beta_i}{\alpha_i} \sum_{j \neq i} \frac{\partial U_i^f / \partial d_j}{U_i'(y_i - a_i)} d_j'(x+x^f) \qquad (15)$$

$$C^{f'}(x^f) = - \sum_i l_i^f \pi_i d_i'(x+x^f) - \sum_i l_i^f \pi_i \sum_{j \neq i} \frac{\partial U_i^f}{\partial d_j} d_j'(x+x^f) \quad \text{with } \pi_i \geq 1 \qquad (16)$$

In both equations, the first terms are common to all mandates, while the second are specific to universal solidarity. We leave it aside for now and start with the adaptative – dynastic case.

Coefficients π_i in equation (16) are ratios between the weighted marginal utility of consumption and the shadow price of abatement at second period. When all contributions a_i^f are strictly positive—i.e., when no country suffers too high damages relative to others—the shadow price of abatement is exactly equal to weighted marginal utility of consumptions in all countries, and weights π_i are equal to one. Hence:

$$C'(x) = - \rho \sum_i l_i^f d_i'(x+x^f) \qquad (17)$$

$$C^{f'}(x^f) = - \sum_i l_i^f d_i'(x+x^f) \qquad (18)$$

Equations (17) and (18) tell us that the only element that matters to determine the level of effort in this case is the world-aggregate marginal damage function $\sum_i l_i^f d_i'(\ )$.

Weights α_i or β_i, on the other hand, do not play a role in setting the absolute level of action (although they are critical for the distribution of expenses, as we've seen above). This supports the previous findings that the debates on absolute level of action and on the distribution of abatement expenditures can be separated at first period. Relatedly, the optimal level of effort does not depend on the distribution of damages. If country-level damages functions change, while the world aggregate

function remains the same, the optimal provision of public goods remains unchanged.

However, (17) and (18) are valid only as long as damages in poor countries are not too high to drop second-period expenditure a_i^f down to zero. Otherwise, the weighted marginal utility of consumption in these countries remains higher than the shadow price of abatement, and weights π_i in these countries are greater than unity. In that case, the optimal level of action is higher, as the planner puts a premium on the damages of the most affected countries.

Numerical simulations (Table 2) suggest however that the variations of level of effort remain modest. At given world aggregate marginal damage function in all scenarios, we allocate more and more of those damages to region S. However, even in the extreme case (f) where damages could wipe up to 12% of revenues in S, against only 2.1% in N, the optimal emission level is up by less than 0.1% compared with the case where both N and S could see 5% of their revenues impacted (scenario a). The intuition behind these results is that, although damages in S are very high relative to N, the evolution of the marginal utility of consumption, which drives the value of weight π_i in S, has a much higher inertia.

How do abatement levels compare in other mandates relative to this mandate? In the status-quo dynastic mandate, total abatement is higher than in the adaptive – dynastic mandate; first period abatement remains virtually unchanged, but second-period abatement rises. The reason is that, in this case, weights π_i have the opposite behavior than in the adaptative dynastic case: they are equal to one in the countries which end up paying all the abatement expenditures (developing countries), while they are greater than one for the others. This raises the total abatement at second period. However, first-period abatement remains virtually unchanged because the implicit discount rate between periods retained by the planner rises as some countries have "overgrowth" compared with the others. For example, keeping the same assumptions as in the paragraph above, the optimal abatement in this mandate is 44% against 43% in the adaptative

dynastic case. First period abatement decreases by 1% (from 7% to 6%) while second period abatement increases from 53% to 55%.

Last, in the adaptative – universal mandate, the volume of abatement also rises. As equations (15) and (16) illustrate, for each level of concentration, and everything else equal, total damages are higher by virtue of the cross-country impacts.[20] The extent to which abatement level increases depends entirely on the specifications of the second-period utilities of the cross-country impacts.

To illustrate, let us assume damages are such that they could wipe up to 2% of the baseline GDP in region N, against 8% in S, and let us compare the adaptative-dynastic case—where all utitilies are logarithmic in local consumption—to the adaptative-universal case where second-period utilities are multiplied by a factor which depends on total damages. This factor is unity when damages are zero, and it increases linearly with total damages, to culminate at 0.99 (a 1% loss of utility) when damages are maximal. In the dynastic setting, the optimal abatement level—on average across both periods—is 33%, and it climbs to 45% in the universal case.

6. Conclusion

The advice that *"equity and efficiency should be separated"* in global environmental issues (Arrow et *al.* 1996) is both in accordance with one basic principle retained in conventional analysis of environmental policies and a way of dissociating the selection of a given level of public good from the *regressum ad infinitum* of ethical controversies induced by any burden sharing negotiation (Hourcade, 1994). This position had been questioned under the argument that the second theorem of welfare does not hold for a privately produced public good since of all the possible ways of distributing a given total of emissions rights, very few are compatible with efficient markets (Chichilnisky et

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[20] We do not consider the possibility here that some countries may benefit from climate change impacts in others.

al., 2000). Chao and Peck (2000) responded that this point was numerically of second order in the case of climate change.

This paper comes back to the non orthogonality between equity and efficiency starting from another angle which may have significant implications. We show that, even under a no redistribution constraint and for a given pure preference for the present, the provision of public good and the optimal distribution of abatement expenditures are governed by a) whether Parties stick or not to the diplomatic reflex of using current balances of power to shape future agreements (status-quo versus adaptative mandate) b) the way in which they envisage their solidarity with future generations (dynastic versus universal).

The first period allocation of abatement expenditures should be governed by the same BLS like principle regardless of the mandate; it is progressive with income for a wide range of utility functions and independent from both the global level of action and the second period distribution of damages. But, for the same expectations about climate damages, the first period abatement is far lower in the status quo – dynastic mandate than in the adaptative-universal solidarity mandate.

At the second period, status quo mandates lead to the paradoxical outcome of charging countries with the highest growth rate (in principle developing countries) and entail risks of non acceptability or of dynamic inconsistency. Adaptative mandate circumvent this trap and comes back to a BLS type rule. However this rule applies to the total of second period expenditures and climate damages which complicates the matter for two reasons: first some countries might be hurt so much that they would not have to contribute at all to second period abatement expenditures; second the uncertainty of science about climate change at a regional level and about resulting economic impacts, is huge.

Even though uncertainty (and its strategic use) does not affect the burden allocation at the first period, it changes significantly the magnitude of the first (and second period) effort depending upon Parties adopting a dynastic or universal solidarity. In the latter case, be for reasons of benevolence, of fear of propagation effects of local

shocks or of non confidence in climate change predictions at a local scale, part of damages expected to fall on a poor country is accounted by rich countries who have a higher weight in the planner's objective function. This explains why, for given sets of 'beliefs' regarding climate change the problems related to uncertainty matter less under this mandate and why the optimal first period action is higher.

This analysis suffers from a number of limitations, in particular because it only considers moves along a Pareto frontier; it examines neither the impact of income distribution of on the production frontier (Guesnerie, 1995) nor no-regret measures (Hourcade et *al.*, 1996) allowing for what Stiglitz (1998) calls "near Pareto improvements". In policy terms however it shows that controversies about equity does not prevent from agreeing on a simple rule of thumb (proportionality to *per capita* revenue) to allocate the costs of producing a global public good. But, and this is a strong assumption, this implies Parties to follow a "universal solidarity" attitude and the wealthiest ones to refrain from using their negotiating power to refuse envisaging the narrowing of gaps in per capita income over the century.

A lot of work remains to be done to translate this rule of thumb through proxies based on observable variables. No such allocation mechanism may suffice in securing equity because of the uncertainty pervading all the parameters at stake and the focus should be placed on the institutional devices apt to face uncertainty (Hourcade and Ghersi, 2002). But, even within a rather conservative no redistribution principle, we provide a tool to assess the equitable character of various package deals and we show that attitudes regarding damages and future generations will ultimately matter more than "ethical intuitions."

Appendix 1: Model Resolution under Certainty

Under certainty, the most general version of the planner's model is as follows:

$$\text{Max} \sum_i l_i \, \alpha_i \, U_i(y_i\text{-}a_i) \; + \varphi \sum_i l_i^f \, \beta_i \, U_i^f(y_i^f\text{-}a_i^f\text{-}d_i(x+x^f),d_1^f,\ldots,d_{i\text{-}1}^f,d_{i+1}^f,\ldots,d_N^f)$$

$$(a1)$$

Under the following constraints:

$$\sum_i l_i \, a_i = C(x) \tag{a2}$$

$$\sum_i l_i^f \, a_i^f = C^f(x^f) \tag{a3}$$

$$a_i \geq 0 \tag{a4}$$

$$a_i^f \geq 0 \tag{a5}$$

$$\alpha_i = \frac{\alpha}{U_i'(y_i)} \qquad\qquad \text{with } \alpha = \left(\sum_i \frac{l_i}{U_i'(y_i)} \right)^{-1} \tag{a6}$$

$$\beta_i = \begin{cases} \alpha_i & \text{in status-quo mandates} \\ \dfrac{\beta}{U_i^f{}'(y_i^f)} & \text{in adaptative mandates} \end{cases} \quad \text{with } \beta = \left(\sum_i \frac{l_i^f}{U_i^f{}'(y_i^f)} \right)^{-1} \tag{a7}$$

Let λ, μ, ξ_i and ψ_i be the Lagrange multipliers attached to constraints (a2) to (a5). The Lagrangean of the problem is:

$$\mathbf{L} = \sum_i l_i \, \alpha_i \, U_i(y_i\text{-}a_i) \; + \varphi \sum_i l_i^f \, \beta_i \, U_i^f(y_i^f\text{-}a_i^f\text{-}d_i(x+x^f),d_1^f,\ldots,d_{i\text{-}1}^f,d_{i+1}^f,\ldots,d_N^f)$$

$$- \lambda[C(x) - \sum_i l_i \, a_i] - \mu \, \varphi \, [C^f(x^f)-\sum_i l_i^f \, a_i^f] - \sum_i l_i \, \xi_i \, a_i - \varphi \sum_i l_i^f \, \psi_i \, a_i^f \tag{a8}$$

At optimum, derivation of $\mathbf{L}$ with regard to a_i yields:

$$\frac{\partial \mathbf{L}}{\partial a_i} = 0 \Leftrightarrow \alpha_i \, U_i'(y_i\text{-}a_i) + \xi_i = \lambda \tag{a9}$$

With

$$\begin{cases} \xi_i = 0 \text{ if } a_i > 0 \\ \xi_i > 0 \text{ if } a_i = 0 \end{cases} \tag{a10}$$

Since weighted marginal utilities of consumption before abatement are equal (a6), there is a solution where all first-period contributions to abatement a_i are strictly positive, with corresponding Lagrange multipliers ξ_i equal to zero.[21]

Derivation of $\mathbf{L}$ with regard to a_i^f yields:

$$\frac{\partial \mathbf{L}}{\partial a_i^f} = 0 \Leftrightarrow \beta_i \frac{\partial U_i^f}{\partial c} (y_i^f \text{-} a_i^f \text{-} d_i(x+x^f),\ldots) + \psi_i = \mu \tag{a11}$$

In adaptative mandates, weights β_i are such that weighted marginal utilities of consumption before abatement are equal. If damages are not too high in some countries, there again exists a solution where all abatement expenditures a_i^f are positive, with Lagrange multipliers ψ_i equal to zero. If damages are too high in some countries, then constraint (a5) becomes binding, and the corresponding abatement expenditures are zero.

In status-quo mandates on the contrary, weights β_i are not likely to be such that the vector y_i^f is welfare maximizing. In that case, the optimal plan is to allocate abatement expenditures to the country which has the lowest before abatement marginal utility of consumption.

Derivation of $\mathbf{L}$ with regard to future abatement x^f level yields:

$$\frac{\partial \mathbf{L}}{\partial x^f} = 0 \Leftrightarrow \mu \, C^{f'}(x^f) = - \sum_i l_i^f \beta_i \frac{\partial U_i^f}{\partial c} d_i^{'}(x+x^f) - \sum_i l_i^f \beta_i \sum_{j \neq i} \frac{\partial U_i^f}{\partial d_j} d_j^{'}(x+x^f) \tag{a12}$$

When none of the constraints (a5) are binding—i.e., in adaptative mandates when damages are not too high—(a11) tells us that Lagrange multiplier μ is equal to the (common) weighted marginal utility of consumption. In that case, (a12) can be simplified in:

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[21] It is easy to demonstrate that this solution is superior to a solution where part, or all of the a_i would be equal to zero.

$$C^{f'}(x^f) = - \sum_i l_i^f\, d_i'(x+x^f) - \sum_i l_i^f \sum_{j \neq i} \frac{\partial U_i^f}{\partial c} \left(\frac{\partial U_i^f}{\partial d_j} \right)^{-1} d_j'(x+x^f) \tag{a13}$$

Abatement at second period should thus be such that it equates the sum of individual marginal damages, plus cross-country impacts, if any (in "universal solidarity" mandates).

If, in adaptative mandates, damages in some countries are too high, then the weighted utility of the countries with high damages is higher than μ. The marginal damage in these countries is thus counted with a coefficient superior to 1.

In status-quo mandates, on the other hand, μ is equal to the weighted marginal utility of the few countries which contribute to abatement expenditures. The weighted marginal utility of all the others is higher than that value, hence giving their marginal damages a higher weight in (a13).

Derivation of **L** with regard to first-period abatement level x yields:

$$\frac{\partial \mathbf{L}}{\partial \mathbf{x}} = 0 \Leftrightarrow \lambda\, C'(x) = - \varphi \sum_i l_i^f \beta_i \frac{\partial U_i^f}{\partial c} d_i'(x+x^f) - \varphi \sum_i l_i^f \beta_i \sum_{j \neq i} \frac{\partial U_i^f}{\partial d_j} d_j'(x+x^f) \tag{a14}$$

Since Lagrange multiplier λ is equal to the weighted marginal utility of consumption at first period, this equation can be written:

$$C'(x) = - \varphi \sum_i l_i^f \frac{\beta_i}{\alpha_i} \frac{\partial U_i^f}{\partial c} \left(\frac{dU_i}{dc} \right)^{-1} d_i'(x+x^f) - \varphi \sum_i l_i^f \frac{\beta_i}{\alpha_i} \sum_{j \neq i} \frac{\partial U_i^f}{\partial d_j} \left(\frac{dU_i}{dc} \right)^{-1} d_j'(x+x^f) \tag{a15}$$

Let us first assume that weights α_i and β_i are equal (the status-quo mandate). Then the marginal cost of abatement at first period is equal the discounted sum of future marginal damages, weighted by the ratios in marginal utility of consumption at second and at first period. The country which marginal utility of consumption has decreased most, that is the country which bears all the abatement expenditures, also has the lowest weight on its marginal damage. Conversely, the

countries with the lowest decrease in marginal utility of consumption sees its marginal damages weighted higher.

In the adaptative mandates, on the other hand, equation (a15)—omitting the second term—becomes:

$$C'(x) = -\, \varphi \sum_i l_i^f \frac{U_i'(y_i)}{\alpha} \frac{\beta}{U_i^f(y_i^f)} \; \frac{\partial U_i^f}{\partial c} (y_i^f - a_i^f - d_i) \left(\frac{dU_i}{dc}(y_i - a_i) \right)^{-1} d_i'(x + x^f) \quad \text{(a16)}$$

If total costs of climate change in all countries and at both periods remain small compared to baseline revenues, then the marginal utility terms cancel out, and remains:

$$C'(x) = -\, \varphi \frac{\beta}{\alpha} \sum_i l_i^f \, d_i'(x + x^f) \qquad\qquad\qquad \text{(a17)}$$

The term $\varphi \dfrac{\beta}{\alpha}$ is approximately equal to the consumption discount rate in that economy. First period abatement costs are thus equal, in that case, to the discounted value of second period abatement costs.

Appendix 2: Model Resolution under Uncertainty

To introduce uncertainty, we assume the planner faces a finite set of possible scenarios indexed by $j \in \{1,2,\ldots,M\}$. Each set is characterized by a specific distribution of climate change impacts d_{ij}, of regional second-period income y_{ij}^f, and of future abatement costs C_j^f. The planner also knows that full information about the true state of the world will be revealed at the beginning of second period. But at the beginning of the first period, the planner only has a set of subjective probabilities p_j attached to each possible future state of the world. Assuming the planner's utility function is Von-Neumann, the optimization problem becomes:

$$\text{Max} \sum_i l_i \, \alpha_i \, U_i(y_i - a_i)$$

$$+ \sum_j p_j \, \varphi \sum_i l_i^f \, \beta_{ij} \, U_i^f(y_{ij}^f - a_{ij}^f - d_{ij}(x + x_j^f), d_{1j}^f, \ldots, d_{i-1\,j}^f, d_{i+1\,j}^f, \ldots, d_{Nj}^f) \qquad \text{(a18)}$$

$$\sum_i l_i \, a_i = C(x) \tag{a19}$$

$$\sum_i l_i^f \, a_{ij}^f = C_j^f(x_j^f) \tag{a20}$$

$$a_i \geq 0 \tag{a21}$$

$$a_{ij}^f \geq 0 \tag{a22}$$

$$\alpha_i = \frac{\alpha}{U_i'(y_i)} \qquad\qquad \text{with } \alpha = \left(\sum_i \frac{1}{U_i'(y_i)}\right)^{-1} \tag{a23}$$

$$\beta_{ij} = \begin{cases} \alpha_i & \text{in status-quo mandates} \\ \dfrac{\beta_j}{U_i^f(y_{ij}^f)} & \text{in adaptative mandates} \end{cases} \qquad \text{with } \beta_j = \left(\sum_i \frac{1}{U_i'(y_{ij}^f)}\right)^{-1} \tag{a24}$$

The Lagrangean becomes

$$\mathbf{L} = \sum_i l_i \, \alpha_i \, U_i(y_i\text{-}a_i) + \varphi \sum_{ij} l_i^f \, p_j \, \beta_{ij} \, U_i^f(y_{ij}^f\text{-}a_{ij}^f\text{-}d_{ij}(x+x_j^f), d_{1j}^f, \ldots, d_{i\text{-}1\,j}^{\,f}, d_{i+1\,j}^{\,f}$$

$$, \ldots, d_{Nj}^f) - \lambda[C(x) - \sum_i l_i \, a_i] - \sum_j p_j \, \mu_j \, \varphi \, [C_j^f(x_j^f) - \sum_i l_i^f \, a_{ij}^f] - \sum_i l_i \, \xi_i \, a_i$$

$$- \varphi \sum_{ij} l_i^f \, \psi_{ij} \, a_{ij}^f \tag{a25}$$

And first-order conditions are now

$$\frac{\partial \mathbf{L}}{\partial a_i} = 0 \Leftrightarrow \alpha_i \, U_i'(y_i\text{-}a_i) + \xi_i = \lambda \tag{a26}$$

$$\frac{\partial \mathbf{L}}{\partial a_{ij}^f} = 0 \Leftrightarrow \beta_{ij} \frac{\partial U_i^f}{\partial c} (y_{ij}^f\text{-}a_{ij}^f\text{-}d_{ij}(x+x_j^f), \ldots) + \psi_{ij} = \mu_j \tag{a27}$$

$$\frac{\partial \mathbf{L}}{\partial x_j^f} = 0 \Leftrightarrow \mu_j \, C_j^{f'}(x_j^f) = - \sum_i l_i^f \, \beta_{ij} \frac{\partial U_i^f}{\partial c} d_{ij}'(x+x_j^f) \quad - \sum_i l_i^f \, \beta_{ij} \sum_{k \neq i} \frac{\partial U_k^f}{\partial d_{kj}} d_{kj}'(x+x_j^f) \tag{a28}$$

$$\frac{\partial \mathbf{L}}{\partial \mathbf{x}} = 0 \Leftrightarrow \lambda\, C'(x) = -\sum_j p_j\, \varphi \sum_i l_i^f\, \beta_{ij}\, \frac{\partial U_i^f}{\partial c}\, d_{ij}'(x+x_j^f)$$

$$-\sum_j p_j\, \varphi \sum_i l_i^f\, \beta_{ij} \sum_{k \neq i} \frac{\partial U_k^f}{\partial d_{kj}}\, d_{kj}'(x+x_j^f) \qquad (a29)$$

Appendix 3: Domain of Validity of Property (12)

Let U be a twice differentiable utility function defined over $\mathbb{R}^+$, with U'>0, U"<0. We are looking for the conditions under which the following property is valid:

(P1) For all x>0 and all y > 0, $x < y \Rightarrow \dfrac{U''(x)}{U'(x)} < \dfrac{U''(y)}{U'(y)}$ $\qquad$ (a30)

For property **P1** to hold, U' be sufficiently convex.[22] We show here that if U"/U' is monotonous, and if U is unbounded, then **P1** holds.

<u>Proof:</u> If U"/U' were decreasing, then we would have (U"/U')' = [ln(U')]" ≤ 0 over $[1,+\infty[$.

Let G be the twice differentiable function such that G(1) = U'(1), [ln(G)]'(1) = [ln(U')]'(1), and [ln(G)]' constant over $[1,+\infty[$. G exists, and is uniquely defined. Precisely, $G(c) = e^{ac+b}$ with a + b = U'(1) and a = [ln(U')]'(1) <0.

Since G(1) = U'(1), [ln(G)]'(1) = [ln(U')]'(1), and [ln(U')]" ≤ 0 while [ln(G)]"=0, we have U'(c) $\leq$ G(c) for all c in $[1,+\infty[$.

But $\int_1^c G(x)\, dx$ is bounded, and thus so is $\int_1^c U'(x)\, dx$, which contradicts the initial assumption that U is not bounded. C.Q.F.D.

Appendix 4:

Let U be a twice differentiable utility function defined over $\mathbb{R}^+$, with $U'>0$, $U''<0$. Let $x_1,\ldots,x_n,y_1,\ldots,y_n$ be strictly positive real numbers with $y_1 > y_i$ for all $i \geq 2$. We want to explore under which conditions the following holds:

$$\textbf{(P2)} \; \frac{U'(y_1 x_1)}{U'(x_1)} < \frac{U'(y_i x_i)}{U'(x_i)} \; \text{for all } i \geq 2 \tag{a31}$$

This is true for all utility functions such that $U'(ac) = a^{-k} U'(c)$ with $a>0$ and $k>0$. That includes, in particular, classical utility functions such as $\ln(c)$, and c^a with $0<a<1$.

For small growth, we have:

$$\frac{U'(c(1+g))}{U'(c)} \approx \frac{U'(c) + U''(c)gc}{U'(c)} = 1 + \frac{U''(c)}{U'(c)}cg \tag{a32}$$

Thus

$$\frac{U'(c_1(1+g_1))}{U'(c_1)} < \frac{U'(c_2(1+g_2))}{U'(c_2)} \quad \text{i.i.f} \; - \frac{U''(c_1)}{U'(c_1)}c_1\, g_1 > - \frac{U''(c_2)}{U'(c_2)}c_2\, g_2 \tag{a33}$$

The property is valid when U''/U' is inversely proportional to wealth. In the other cases, the problem is more difficult. If the country to grow at faster rate is also the country with lowest initial wealth level ($c_1 < c_2$, $g_1 > g_2$), then the property is valid for functions where $- c\, U''/U'$ is decreasing with wealth. When $- c\, U''/U'$ is increasing with wealth, then the result is ambiguous.[23]

Appendix 5: Numerical Illustration

We consider two regions, called "North" and "South" respectively. "North" comprises high-income countries, as per World Bank (2002) definition, and "South" low and middle income ones. First period is

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[23] In the literature on attitudes towards risk, $- c\, U''/U'$ is the relative risk aversion. The property holds for constant relative risk aversion, and decreasing risk aversion functions. It is ambiguous for increasing risk aversion ones.

2000-2050, and second period 2050-2100. First-period income and population data are given by World Bank (2002).[24] In the baseline scenario, economic growth in the North is assumed to be 2.5% per year, against 3% in the South. World population is assumed to grow by 2 billions people, all of them in the developing world. Table 2 summarizes key economic parameters in the baseline scenario.

Carbon dioxide emissions in the baseline assumed to reach 500 $GtCO_2$ during the first period, and 700 $GtCO_2$ during the second one. Abatement costs at first and second period are assumed quadratic with respect to total abatement expenditures:

$$x = 500 \left(1 - 3 \sqrt{\frac{l_n \, a_n + l_s \, a_s}{l_n \, y_n + l_s \, y_s}} \right) \tag{a34}$$

$$x^f = 700 \left(1 - 6 \sqrt{\frac{l_n^f \, a_n^f + l_s^f \, a_s^f}{l_n^f \, y_n^f + l_s^f \, y_s^f}} \right) \tag{a35}$$

Damages are assumed to be cubic with the total amount of carbon emitted in the atmosphere $x + x^f$. We will use several sets of coefficients ($\theta_{north}, \theta_{south}$) to simulate several possible distribution of damages across countries.

$$d_i^f(x + x^f) = \theta_i \left(\frac{x + x^f}{1200} \right)^3 \tag{a36}$$

All utility functions are assumed to be logarithmic in consumption. The utility discount rate is set at 1% per year.

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[24] For simplicity's sake, we use 2000 and 2050 data respectively as averages for the two periods.

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Table 1: Second-Period Expenditures in Adaptative – Dynastic Mandates

Scenario	y_N	y_S	θ_N	θ_S	$\dfrac{a_N}{y_N}$	$\dfrac{d_N}{y_N}$	$\dfrac{a_N}{y_N}+\dfrac{d_N}{y_N}$	$\dfrac{a_S}{y_S}$	$\dfrac{d_S}{y_S}$	$\dfrac{a_S}{y_S}+\dfrac{d_S}{y_S}$
a	91.94	5.09	$0.05\,y_N$	$0.05\,y_S$	1.00%	1.18%	2.18%	1.00%	1.18%	2.18%
b	91.94	5.09	$0.04\,y_N$	$0.06\,y_S$	1.08%	1.01%	2.09%	0.57%	1.52%	2.09%
c	91.94	5.09	$0.03\,y_N$	$0.07\,y_S$	1.17%	0.82%	1.99%	0.08%	1.91%	1.99%
d	91.94	5.09	$0.02\,y_N$	$0.08\,y_S$	1.09%	0.59%	1.68%	0%	2.38%	2.38%

In scenario (a), climate change rips the same share of baseline revenue in the North and in the South (5% if no abatement occurs). Starting from scenario (b), damages as a share of baseline revenues become higher in the South than in the North, with respectively 4%/6%, 3%/7% and 2%/8% if no abatement occurs.

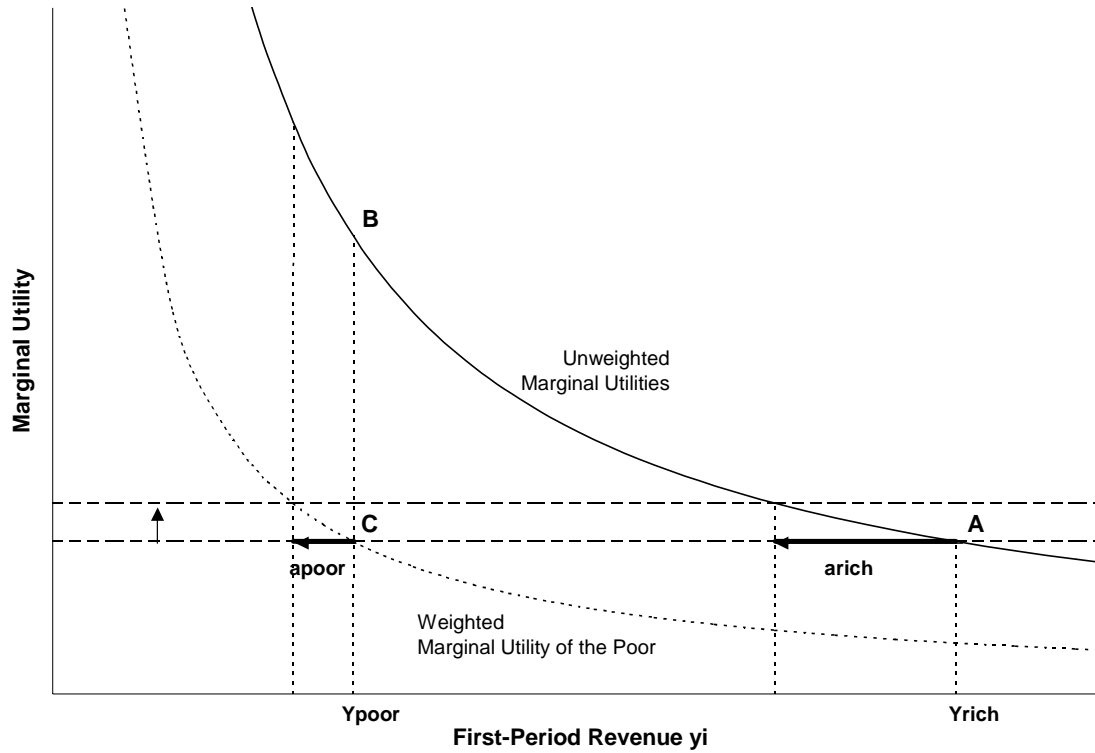**Table 2: Total Abatement Level in Adaptative Dynastic Mandate**

	θ_N (% y_N^f)	θ_S (% y_S^f)	Total Emissions x+xf	Second-Period Climate bill N	Second-Period Climate bill S
a	5.0%	5.0%	743.4	2.20%	2.20%
b	4.4%	6.4%	743.4	2.20%	2.20%
c	3.9%	7.8%	743.4	2.20%	2.20%
d	3.3%	9.1%	743.4	2.20%	2.20%
e	2.7%	10.5%	742.8	2.08%	2.50%
f	2.1%	11.9%	742.1	1.95%	2.83%
g	1.6%	13.3%	741.2	1.81%	3.15%
h	1.0%	14.7%	740.2	1.69%	3.45%
i	0.4%	16.1%	739.2	1.56%	3.75%
j	0.0%	17.0%	738.2	1.47%	3.97%

In all scenarios, the total world damage is constant, and only its distribution varies in such a way that the population weighted marginal damage remains constant. In scenarios a to d, damages are such that both north and south contribute at second period (see Appendix 3 for assumptions underlying this analysis). Total emissions $x+x^f$ are equal. From scenario e onward, damages are too high in the South, and climate bills relative to income can no longer be equalized. However, although the wedge between north and south damages rises sharply, total cumulative emissions $x+x^f$ decline only very little (less than one per cent).

Table 3: Economic and Population Assumptions

	2000		2050	
	l_i (billions)	y_i (1995 US$)	l_i^f (billions)	y_i^f (1995 US$)
North	0.95	26,750	0.95	91,943
South	5.11	1,160	7.11	5,085

Figure 1: Optimal abatement levels for the poor and for the rich region at first period

p

Figure 2: Optimal abatement levels for the poor and for the rich region at second period