Negotiation processes for the protection of biodiversity

Very preliminary. Do not quote.

Stéphanie Aulong[*], Charles Figuières[†] and Robert Lifran[‡]

August 27, 2004

Abstract

Consider a developing country that has the potential for biodiversity conservation, and developed countries that benefit from biodiversity but are not in position to produce it. From the *statu quo*, some incremental protections of biodiversity would be harmful for the developing country but would benefit the developed contries and the world as a whole; in other words, biodiversity protection is a global public good. The negotiation problem is then: how to organize compensation transfers from the developed countries to the developing country to to sustain a higher (Pareto optimal) level of biodiversity, given that: i) each developed country has an incentive to free-ride on transfers conceded by others, ii) no supranational authority exists that has both the necessary relevant information on countries's willingness to pay for biodiversity, and the power to impose a socially beneficial profile of transfers? This paper investigates how, and to what extent, the theory of resource allocation process can shed light into this issue. The focus is put on the incentive properties of the suggested negotiation processes, and their ability to respect countries' sovereignty.

[*]Station biologique de la Tour du Valat and UMR LAMETA. Email: aulong@ensam.inra.fr

[†]Corresponding author. INRA, UMR LAMETA, 2 place Viala, 34060 Montpellier, cedex 1. France. Email: figuiere@ensam.inra.fr

[‡]INRA, UMR LAMETA. Email: lifran@ensam.inra.fr

1 Introduction

Consider a developing country that has the potential for biodiversity conservation, and developed countries that benefit from biodiversity but are not in position to produce it. From the statu quo, some incremental protections of biodiversity would be harmful for the developing country but would benefit the developed countries and the world as a whole[1]. Such a situation calls for compensation transfers from the developed countries to the developing country to sustain a higher (Pareto optimal) level of biodiversity. The difficulties attached to such a solution are well understood: i) each developed country has an incentive to free-ride on transfers conceded by others, ii) no supranational authority exists that has both the necessary relevant information on countries's concerns about biodiversity, and the power to impose a socially beneficial profile of transfers.

Barrett (1994) suggests that countries may find their ways to a Pareto optimal outcome without the intervention of any public authority. His argument rests on the possibility for countries to devise trigger strategies, whereby each country contributes a Pareto optimal level of transfers as long as no deviation from any other country is detected; such a deviation would trigger a punishment by a fall back to a non cooperative play, which is harmful for the deviator. Conditions are identified for the above strategies to form a negotiation-proof Nash equilibrium. The possibility also exists of trigger equilibrium strategies that are Pareto improving over the static Nash equilibrium.

In this paper we depart from the above repeated game argument in two important ways. Firstly, we relax the assumption of super-rational agents who are able to contemplate highly sophisticated strategies in order to maximize their discounted total payoff; instead we assume that the countries are naive, in the sense that when choosing an action, they do so only on the basis of its immediate effect, one period ahead. Secondly, an institution (traditionally called a *planning bureau* in the related literature, and which we prefer to call an *international agency*) organizes the exchange of key pieces of information with the hope to implement Pareto improving changes as a function of the collected data. The question we ask is: could a Pareto optimal level of biodiversity emerge from a negotiation process organized by an international agency that is able to respect countries' sovereignty and to neutralize the countries' temptation to manipulate the information?

Put another way, our paper stands at the intersection of two strands of literature. It first belongs to the economic literature on Biodiversity, providing theoretical answers for issues in relation with the organization of financial transfers from developed to developing countries. It also, modestly, contributes to the dynamic theory of resources allocation, with the introduction of a majority voting scheme into a discrete-time process. The resulting process builds on an earlier one, proposed by Champsaur, Drèze Henry (1977), and further studied by Schoumaker (1979), who focused on the agents' incentives to manipulate

[1] Biodiversity has a global public good dimension, as emphasized in the Fifth Revised Draft Convention on Biological Diversity, signed in 1992.

the exchange of information with the institution. The proposed institutional framework looks like actual institutions such as the Global Environmental Facility (GEF) created in 1991. The GEF is an independent financial organization that provides grants to developing countries for projects that benefit the global environmental and promote sustainable livelihoods in local communities". GEF's projects address six global environmental issues, one of which is biodiversity. The major financial tool of the Convention on Biological Diversity is the GEF fund. GEF's contributors are voluntary donors, most of whom are States. It funds the "incremental" or additional costs associated with transforming a project with national benefits into one with global environmental benefits.

The discussion is structured as follows. The following section formalizes the particular aspect of the biodiversity issue we want to investigate, and illustrates the free-rider problem. Section 3 explains what answers can be provided by the dynamic theory of resources allocation. The proposed procedure can be given the interpretation of a negotiation process. Section 4 qualifies the process by introducing a voting scheme. The last section concludes.

2 Modelling the financing of biodiversity as a public good

The problem is modelled along the lines of Barrett (1994). Consider one developing country (country 0) that has the potential for biodiversity conservation, and n developed countries (labeled country $1, 2, ..., n$) that benefit from biodiversity but are not in position to produce it, generally for geographical and climatic reasons. Let S^* stands for the units of biodiversity that the developing country is willing to protect unilaterally[2]. By definition of S^*, any incremental protection of biodiversity, S, in an admissible interval[3] $\left]0, \overline{S}\right]$, is detrimental for country 0, and this will be interpreted as the developing country's cost of conserving biodiversity, which we shall assume to be a strictly increasing and convex function: $C(S)$, with $C'(S) > 0, C''(S) \geq 0,\ S \in \left]0, \overline{S}\right]$.

For a developed country i, the benefits of conserving additional units of global biodiversity above S^* are given by:

$$B^i(S), \quad i = 1, ..., n, \tag{1}$$

a concave function, increasing for all $S \in \left]0, \overline{S}\right]$.

Let M_i denotes a money transfer from developed country i to country 0. This transfer is paid out of country i's exogenous income w_i. If $y_i = w_i - M_i$ stands for the income left for any other use, the net benefits of developed country i read as:

$$NB^i\left(S, y_i\right) = B^i(S) + y_i\ . \tag{2}$$

[2] Units of biodiversity are treated here as positive real numbers.

[3] The upper bound $\overline{S}$ is exogenously given. If S is to be interpreted as the number of acres devoted to wilderness, clearly this number cannot go to infinitum.

The aggregate payment made by the developed countries is $M = \sum M_i$, a *Global Biodiversity Conservation Fund* in the words of Barrett (1994). This fund is meant to cover country 0's cost, therefore $M = C(S)$; since there is an upper bound on S, there is an upper bound on the amount of money that can be collected for the protection of biodiversity, i.e. $\overline{M} = C\left(\overline{S}\right)$. To simplify, it will be assumed that countries' endowments w_i are such that $\sum w_i \leq \overline{M}$. Also, for a given M, and since the cost function is invertible, we can express:

$$S = C^{-1}(M), \tag{3}$$

which is the affordable level of biodiversity conservation when the payments sum-up to M. Country i's net benefits can be restated as:

$$\begin{aligned} NB^i\left(M_i, M_{-i}\right) &= B^i(C^{-1}(M_i + M_{-i})\ ) + w_i - M_i, &(4)\\ &= \Phi^i(M_i + M_{-i}) + w_i - M_i &(5) \end{aligned}$$

where $M_{-i} = \sum_{j \neq i} M_j$, and $\Phi^i = B^i \text{o} C^{-1}$. With the assumptions made on B^i and C, the function Φ^i is increasing and concave over the admissible range for M. We shall also make the following assumption to ensure the existence of interior Pareto outcomes and Nash equilibria:

$$\lim_{M \to 0} B^{i\prime} C^{-1\prime}\left(M\right) > 1 \quad \text{and} \quad \lim_{M \to \sum w_i} B^{i\prime} C^{-1\prime}\left(M\right) < 1.$$

This is a classical model of voluntary contributions to a public good, M, where the marginal cost to produce this public good is 1.

Contributions are Pareto optimal, or efficient, when they satisfied the Bowen-Lindhal-Samuelson conditions; here those conditions require that the sum of countries marginal benefits from the Conservation Fund is equal to its marginal cost , i.e.

$$\sum_{i=1}^{n} \Phi^{i\prime} = 1\ . \tag{6}$$

On the other hand, a voluntary (Nash) contributions equilibrium is characterized by the following marginal conditions:

$$\Phi^{i\prime} = 1\ ,\ i = 1, ..., n. \tag{7}$$

From expressions (11) and (7), one can deduce that voluntary contributions are not efficient.

The following example allows further precision.

Example 1 *Barrett (1994) dealt only with the following example. Let the associated cost for country* 0 *be* $C(S) = cS^2/2,\ c > 0$.

For a developed country i*, the benefits of conserving additional units of global biodiversity are given by:*

$$B^i\left(S\right) = \frac{b}{n}\left(a_i\, S - \frac{S^2}{2}\right)\ ,\ \ b, a_i > 0,\ \ i = 1, ..., n, \tag{8}$$

a concave function, increasing for all $S \in [0, a_i]$ *. It should be noted that country* $i's$ *benefits depend on the number of participants,* n*.*

Therefore the net benefits of developed country i *read as:*

$$NB^i\left(S, y_i\right) = \frac{b}{n}\left(a_i\, S - \frac{S^2}{2}\right) + y_i \ . \tag{9}$$

The affordable increment of biodiversity, given the overall payments received by the developing country $M = \sum M_i$*, is:*

$$S = \sqrt{\frac{2M}{c}} \ . \tag{10}$$

Plugging (10) into (9), country i*'s net benefits are:*

$$\frac{b}{n}\left[a_i\,\left(\frac{2\left(M_i + M_{-i}\right)}{c}\right)^{1/2} - \frac{M_i + M_{-i}}{c}\right] + w_i - M_i \ .$$

The Bowen-Lindhal-Samuelson conditions are then

$$\sum_{i=1}^{n} \frac{b}{n}\left[\frac{a_i}{c}\left(\frac{2\left(M_i + M_{-i}\right)}{c}\right)^{-1/2} - \frac{1}{c}\right] = 1 \ . \tag{11}$$

And the voluntary (Nash) contributions equilibrium solves:

$$\frac{b}{n}\left[\frac{a_i}{c}\left(\frac{2\left(M_i + M_{-i}\right)}{c}\right)^{-1/2} - \frac{1}{c}\right] = 1. \tag{12}$$

From expressions (11) and (12), voluntary contributions are clearly not efficient. Often, the voluntary contributions equilibrium falls short of the social optimum. This last property holds and is particularly easy to check in the symmetric case, where countries are identical so that $a_i = a\,, \forall i$*; then (11) becomes:*

$$b\left[\frac{a}{c}\left(\frac{2\left(M\right)}{c}\right)^{-1/2} - \frac{1}{c}\right] = 1 \ ,$$

and gives the efficient levels of transfers and units of biodiversity:

$$\widehat{M} = \frac{a^2 b^2 c}{2(b+c)^2} \ , \quad \widehat{S} = \frac{ab}{(b+c)} \ .$$

Note that there exists an infinite number of combinations for national contributions that are consistent with the above levels, i.e. $\hat{M} = \sum M^i$ *is unique but the* $M^i s$ *are not. In other words, there is an infinity of Pareto optima. Also the first order conditions for a voluntary Nash equilibrium now read as:*

$$\frac{b}{n}\left[\frac{a}{c}\left(\frac{2M}{c}\right)^{-1/2} - \frac{1}{c}\right] = 1 \ ,$$

which yields the following transfers and units of biodiversity:

$$\overline{M} = \frac{a^2b^2c}{2(b+nc)^2}\ , \quad \overline{S} = \frac{ab}{(b+nc)}\ .$$

When there are at least two developed countries, from the above expressions one readily deduces the following intuitive inequalities:

$$\overline{M} < \widehat{M}\ , \quad \overline{S} < \widehat{S}\ .$$

3 Negotiation processes to move to a social optimum

The question we want to challenge now is how to induce the countries to move from the inefficient voluntary contributions equilibrium, or any other inefficient starting point, to an efficient outcome, given a number of constraints, mainly of informational nature? This is a classical implementation problem. The literature on mechanism design has suggested a number of mechanisms that somehow solve the problem; one such mechanism based on a process approach has attracted our attention, for it can be given a negotiation interpretation[4]. It is also appealing on several other counts, which we shall develop below.

The approach rests on a sequence of small size changes. Changes are decided by a *international agency*, conditionally on the result of an exchange of information with the developed countries: a biodiversity increment is proposed by the international agency and countries are asked whether (and eventually how much) they value this change. After collection of those local data, the proposed change is, or is not, implemented by the international agency, according to a rule which is common knowledge. Desired properties of the sequence of changes are: i) their repetition drives the economy from any arbitrary starting point (for instance the voluntary contributions equilibrium) to a Pareto efficient state that is universally preferred to the starting point, ii) the international agency need not know the national interests in Biodiversity conservation that are parameters of asymmetric information (in Example 1, those parameters are the a_is, and we shall assume that the parameter c is public knowledge[5]).

This sequential approach could be contrasted with one-shot approaches characterized by a direct jump from the prevailing situation to the target. The former has a more realistic flavor, but it rests on the implicit assumption that some unspecified constraints hinder a direct jump. As an effort to justify those constraints, it has been argued that one-shot changes require that agents communicate to the international agency their entire utility functions, that is, larger-size messages than those required to convey local data; if the agents' per-period budget constraints cannot cover the associated costs to collect and transmit the data, this can be seen as an economic justification for small-size messages.

[4] For the negotiation interpretation, see Tulkens (1978)' survey, in particular Section 4, and Chander and Tulkens (1992).

[5] This assumption could easily be relaxed. It would introduce no new conceptual difficulties.

3.1 The procedure given correct reports of private pieces of information

In order to facilitate the explanation of the procedure, this section deals with honest countries, i.e. countries that truthfully report their private information when they are asked to. But we shall investigate the case where countries can strategically report in the next subsections, and by contrast, emphasize the issue of manipulation of information.

Consider an arbitrary state of affairs $(S, y_1, ..., y_n)$, and suppose the international agency is contemplating the possibility to change the level of biodiversity fund S by an amount s. The international agency asks each country two pieces of information:

- what is the maximum amount of money country i is willing to give up to enjoy a level of biodiversity $S + s$? If m_i^+ denotes the amount that will leave country i's net benefits unchanged, upon truthful report it is by definition a solution to the equation:

$$NB^i(S, y_i) = NB^i\left(S + s, y_i - m_i^+\right)$$

Example 2 (Example 1 continued) *Using Barrett's framework, the above equation gives*

$$\frac{b}{n}\left[a_i\ S - \frac{S^2}{2}\right] + y_i = \frac{b}{n}\left[a_i\ (S + s) - \frac{(S + s)^2}{2}\right] + y_i - m_i^+\ ,$$

or

$$m_i^+ = \frac{b}{n}\left[a_i - \frac{2S + s}{2}\right]\ s\ .$$

- what is the minimum amount of money required by country i to compensate a reduction of biodiversity to the level $S - s$? Honest countries would report a number m_i^- that solves

$$NB^i(S, y_i) = NB^i\left(S - s, y_i + m_i^+\right)$$

Example 3 (Example 1 continued)

$$\frac{b}{n}\left[a_i\ S - \frac{S^2}{2}\right] + y_i = \frac{b}{n}\left[a_i\ (S - s) - \frac{(S - s)^2}{2}\right] + y_i + m_i^-\ ,$$

or

$$m_i^- = \frac{b}{n}\left[-a_i + \frac{2S - s}{2}\right]\ s\ .$$

Then the international agency computes:

- γ^+, the cost to increase the biodiversity protection up to the level $S+s$, that is $C(S+s)-C(S)$,
- and γ^-, the money saved by reducing the level of biodiversity down to $S-s$, formally $C(S)-C(S-s)$.

There are then three mutually exclusive possibilities[6]:

1. $\sum m_i^+ - \gamma^+ > 0$,
2. $\sum m_i^- - \gamma^- < 0$,
3. $\sum m_i^+ - \gamma^+ \leq 0$ and $\sum m_i^- - \gamma^- \geq 0$.

If situation 1 occurs, the international agency increases the level of biodiversity to $S+s$ and each country is asked to pay m_i^+ to cover the cost. Besides he receives a share $\delta^i \geq 0$ $\left(\text{with } \sum \delta^i = 1\right)$ of the social surplus $\sum m_i^+ - \gamma^+$. Therefore its net benefits in the new situation are:

$$NB^i\left(S+s, y_i - m_i^+\right) + \delta^i\left(\sum m_i^+ - \gamma^+\right) = NB^i\left(S, y_i\right) + \delta^i\left(\sum m_i^+ - \gamma^+\right)$$

The right hand side of this equality follows from the definition of m_i^+, and clearly shows that no country experiences a decrease in utility after the change.

If situation 2 occurs, and provided that $s \leq S$, the international agency decreases the level of biodiversity to $S-s$. If $s > S$ then S is cut down to zero. Each country is paid $m_i^- - \delta^i\left(\sum m_i^- - \gamma^-\right)$. Country i's net benefits in the resulting situation are:

$$NB^i\left(S-s, y_i + m_i^-\right) - \delta^i\left(\sum m_i^- - \gamma^-\right) = NB^i\left(S, y_i\right) - \delta^i\left(\sum m_i^- - \gamma^-\right)$$

Again the definition of m_i^- is used to obtain this equality, which shows that every country gains from the change.

In any other situation, either the procedure stops, or the level of biodiversity is not changed but the increment s is divided by two.

More compactly, and expliciting the temporal dimension of the variables, the dynamics describing the process are:

$$s_{t+1} = \begin{cases} s_t & \text{if either } \sum_i m_{i,t}^+ - \gamma_t^+ > 0\,, \quad (i) \\ & \text{or } \sum_i m_{i,t}^- - \gamma_t^- < 0, \qquad\quad (ii) \\ \frac{s_t}{2} & \text{otherwise.} \end{cases}$$

$$S_{t+1} = \begin{cases} S_t + s_t & \text{if } (i) \text{ holds,} \\ \max\{0, S_t - s_t\} & \text{if } (ii) \text{ holds,} \\ S_t & \text{otherwise.} \end{cases}$$

$$y_{t+1}^i = \begin{cases} y_t^i - m_{i,t}^+ + \delta^i\left(\sum_i m_{i,t}^+ - \gamma_t^+\right) & \text{if } (i) \text{ holds}\,, \\ y_t^i + m_{i,t}^- - \delta^i\left(\sum_i m_{i,t}^- - \gamma_t^-\right) & \text{if } (ii) \text{ holds}\,, \\ y_t^i & \text{otherwise.} \end{cases}$$

[6] Explanations are given in Champsaur, Drèze and Henry (1977) on page 285; see also Schoumaker (1979), page 368.

with $\delta_i \geq 0, \sum_i \delta_i = 1$.

It can be shown that this procedure leads to a Pareto optimum (Champsaur, Drèze and Henry (1977)), and countries benefits are non decreasing along the procedure, as explained above. At a steady state $s_t = 0$, $S_{t+1} = S_t$; also $\lim_{t\to+\infty} y_{t+1} - y_t = -m^i + \delta^i \left(\sum_i m_i - \gamma\right) = 0$, which means that all countries ends up contributing the same effort for biodiversity conservation in the long run, whatever their differences in income w_i, their interest in the environment a_i, and their share of the surplus δ_i.

3.2 Incentive properties of the procedure

How are we to think that countries will report their private information truthfully? And what if they typically do not so? This issue is viewed as a non-cooperative game with the reports $\phi^+_{i,t}$ and $\phi^-_{i,t}$ as countries' strategies and the benefits from the resulting allocation as payoffs. Here the assumption is made that countries are naive, for they ignore all the possible effects of their reports more than one period ahead. Would the reports be equal to the true local data $m^+_{i,t}$ and $m^-_{i,t}$? In the continuous-time version of the procedure, the question has been investigated by Roberts (1979), who shown that, at the unique Nash equilibrium, agents misreport their true data, yet the convergence property to a Pareto optimal allocation does not collapse. Schoumaker (1977), in the discrete-time version, obtained the more precise information that $\phi^+_{i,t} \leq m^+_{i,t}$ and $\phi^-_{i,t} \geq m^-_{i,t}$, a similar result with one difference though. The Nash equilibrium of the message game is not unique; rather there is a continuum of Nash equilibria. Although the other nice properties of the continuous-time process are maintained in the discrete-time version, this multiplicity of equilibria raises an important coordination problem.

In the next Subsection we shall introduce a majority voting in the procedure to overcome this issue. A similar majority voting scheme has been analyzed in the continuous-time process by Green and Laffont (1979), who showed that there is still convergence to a Pareto optimum, but the individual rationality property is lost. Our challenge is twofold: first it is to offer an adequate discrete-time version of majority voting in such processes; second, it is to ascertain the robustness (or the lack) of the properties of convergence and individual rationality. The discussion above makes clear that one cannot infer those properties hold in the discrete-time formulation on the mere basis that they hold in the continuous-time formulation. Besides, we shall see that further details about the agents' behavior are necessary.

3.3 A majority voting procedure

Assume there is an odd number of developed countries $n > 2$. Starting from a situation where there is no incremental protection of biodiversity, within each time period, developed countries are offered the possibility to vote for increasing the biodiversity level of an exogenous positive increment s_t, against the *statu* *quo*; they are also offered the possibility to vote for decreasing the biodiversity level of the same increment s_t, against the *statu quo*[7].

Let v_t^i denote country i's first vote, which can take two values:

$$v_t^i = \begin{cases} 1 & \text{to vote for an increase } S_{t+1} = S_t + s_t \,, \\ 0 & \text{to vote for } S_{t+1} = S_t \,. \end{cases} \tag{13}$$

Similarly, w_t^i denotes country i's second vote, which can also take two values:

$$w_t^i = \begin{cases} 1 & \text{to vote for a decrease } S_{t+1} = S_t - s_t \,, \\ 0 & \text{to vote for } S_{t+1} = S_t \,. \end{cases} \tag{14}$$

At each point of time, countries are randomly affected to v-votes and w-votes. More precisely, there is a random share of countries that are asked first to vote for an increase, and then to vote for a decrease; the remaining share of countries does the same votes in the opposite order. This trick is used to prevent any strategic manipulation of the second votes by the first votes.

The new procedure also specifies that the cost of an eventual increment of biodiversity is shared equally among the countries, that is each country bears $\frac{\gamma_t^+}{n}$. Identically the gain of cost to decrease the level of biodiversity is shared equally, so each country would benefit from $\frac{\gamma_t^-}{n}$.

When $\sum_i v_t^i > (n-1)/2$ the majority calls for an increase of S. When $\sum_i w_t^i > (n-1)/2$ the majority prefers to decrease S. Otherwise the level of biodiversity remains the same, but the increment is halved.

A v_t^i-vote is *truthful* if

$$v_t^i = \begin{cases} 1 & \text{when } m_{i,t}^+ > \frac{\gamma_t^+}{n} \,, \\ 0 & \text{otherwise} \,. \end{cases} \tag{15}$$

and a w_t^i-vote is *truthful* if

$$w_t^i = \begin{cases} 1 & \text{when } m_{i,t}^- < \frac{\gamma_t^-}{n} \,, \\ 0 & \text{otherwise} \,. \end{cases} \tag{16}$$

Assumption 4 *When a country i gets the same utility by voting $v_t^i = 1$ or $v_t^i = 0$, if $m_{i,t}^+ > \gamma_t^+/n$ it chooses $v_t^i = 1$. If $m_{i,t}^+ \leq \gamma_t^+/n$, it chooses $v_t^i = 0$.*

Assumption 5 *When a country i gets the same utility by voting $w_t^i = 1$ or $w_t^i = 0$, if $m_{i,t}^- > \gamma_t^-/n$ it chooses $v_t^i = 0$. If $m_{i,t}^- \leq \gamma_t^+/n$, it chooses $w_t^i = 1$.*

Those two behavioral assumptions can be given the interpretation of some form of *strategic-risk aversion*. They both say that, when the strategic uncertainty can entail a reduction of utility, countries prefer to vote for the *statu quo*.

[7] Note that the procedure is very similar to that of the referendum in the case of an indivisible project.

Proposition 6 *Under Assumptions 4 and 5, truthful voting is a dominant strategy for every country.*

Proof. Consider the situation from the point of view of country i when $m^{+}_{i,t} > \gamma^{+}_{t}/n$. Given the votes of the other countries, if $\sum_{j\neq i} v^{j}_{t} > (n-1)/2$, whatever v^{i}_{t} the net increase of utility is $m^{+}_{i,t} - \gamma^{+}_{t}/n > 0$; if $\sum_{j\neq i} v^{j}_{t} \leq (n-1)/2$ and $\sum_{h} v^{h}_{t} > (n-1)/2$ then $v^{i}_{t} = 1$ produces a net increase of utility of $m^{+}_{i,t} - \gamma^{+}_{t}/n > 0$, and $v^{i}_{t} = 0$ produces no gain; finally if $\sum_{j\neq i} v^{j}_{t} \leq (n-1)/2$ and $\sum_{h} v^{h}_{t} \leq (n-1)/2$ then $v^{i}_{t} = 1$ and $v^{i}_{t} = 0$ both produce no gain. Therefore, whatever the v-votes of the other countries, under Assumption 4 the best plan for country i is to vote $v^{i}_{t} = 1$.

If on the contrary $m^{+}_{i,t} \leq \gamma^{+}_{t}/n$, when $\sum_{j\neq i} v^{j}_{t} > (n-1)/2$, whatever v^{i}_{t} the net loss of utility is $m^{+}_{i,t} - \gamma^{+}_{t}/n \leq 0$; if $\sum_{j\neq i} v^{j}_{t} \leq (n-1)/2$ and $\sum_{h} v^{h}_{t} > (n-1)/2$, then $v^{i}_{t} = 1$ produces a net loss of utility of $m^{+}_{i,t} - \gamma^{+}_{t}/n < 0$, whereas $v^{i}_{t} = 0$ produces no loss; finally if $\sum_{j\neq i} v^{j}_{t} \leq (n-1)/2$ and $\sum_{h} v^{h}_{t} \leq (n-1)/2$ then $v^{i}_{t} = 1$ and $v^{i}_{t} = 0$ both produce no loss. This time, whatever the v-votes of the other countries, the best plan for country i is to vote $v^{i}_{t} = 0$.

The proof for w-votes follows the same logic. ■

Assumption 7 *At each point of time, the distribution of the (true) willingness to pay $m^{+}_{i,t}$, and the distribution of (true) compensations to accept $m^{-}_{i,t}$ are such that the average equals the median.*

In Example 1, this assumption takes a simple form: it is satisfied when the distribution of the parameters a_is is such that the average equals the mean. From Assumption 7 it follows that, at each instant, the distribution of the willingness to pay for increasing biodiversity net of the imputed cost, $m^{+}_{i,t} - (1/n)\gamma^{+}_{t}$, is such that the median equals the mean. This property also holds, at each instant, for the distribution of the compensations for biodiversity reduction net of the imputed gain, $m^{-}_{i,t} - (1/n)\gamma^{-}_{t}$.

Since reporting the truth is a dominant strategy for all countries, one has

Proposition 8 *At a Nash equilibrium of the voting game, under Assumption 7*

$$\sum_{i} v^{i}_{t} > \frac{n-1}{2} \quad \Leftrightarrow \quad \sum_{i} m^{+}_{i,t} > \gamma^{+}_{t} \,,$$

and

$$\sum_{i} w^{i}_{t} > \frac{n-1}{2} \quad \Leftrightarrow \quad \sum_{i} m^{-}_{i,t} < \gamma^{-}_{t} \,.$$

As a corollary of the above proposition, it is important to realize that, at each moment, there cannot be a majority for both an increase and a decrease. Indeed, remember that only one of the following three situations is possible:

1. $\sum m^{+}_{i,t} - \gamma^{+}_{t} > 0$,

2. $\sum m_{i,t}^{-} - \gamma_t^{-} < 0$,

3. $\sum m_{i,t}^{+} - \gamma_t^{+} \leq 0$ and $\sum m_{i,t}^{-} - \gamma_t^{-} \geq 0$.

What can be the effect of the voting scheme in each situation? If situation 1 prevails, from Proposition 8 the outcome of the v-vote is a majority for the increase; and the w-vote will result in the *statu quo*. Symmetrically, in situation 2 the v-vote outcome is the *statu quo*, whereas the w-vote outcome is an decrease of S. Finally in situation 3, both votes produce the *statu quo*.

After collection of v and w-votes, the procedure increases (decreases) the biodiversity level by s_t if there is a majority which favors either option; otherwise the step size is halved. Symbolically, the dynamics are:

$$s_{t+1} = \begin{cases} s_t & \text{if either } \sum_i m_{i,t}^{+} - \gamma_t^{+} > 0\,, \quad (i) \\ & \text{or } \sum_i m_{i,t}^{-} - \gamma_t^{-} < 0, \quad (ii) \\ \frac{s_t}{2} & \text{otherwise.} \end{cases}$$

$$S_{t+1} = \begin{cases} S_t + s_t & \text{if } (i) \text{ holds,} \\ \max\{0, S_t - s_t\} & \text{if } (ii) \text{ holds,} \\ S_t & \text{otherwise.} \end{cases}$$

$$y_{t+1}^{i} = \begin{cases} y_t^i - \gamma_t^{+}/n & \text{if } (i) \text{ holds}\,, \\ y_t^i + \gamma_t^{-}/n & \text{if } (ii) \text{ holds}\,, \\ y_t^i & \text{otherwise.} \end{cases}$$

At each step where the increment is not halved, the process creates a surplus ($\sum_i m_{i,t}^{+} - \gamma_t^{+}$ or $\gamma_t^{-} - \sum_i m_{i,t}^{-}$). But it is not redistributed, contrary to the process outlined in Section 3.1. For this reason, some countries may suffer from the proposed change. Actually, a voted increase is harmful for countries such that $m_{i,t}^{+} - \left(\frac{1}{n}\right)\gamma_t^{+} < 0$, and a voted decrease is harmful for countries characterized by $m_{i,t}^{-} - \left(\frac{1}{n}\right)\gamma_t^{-} > 0$. The sharing rule could be modified to take into account of further information on countries, when available, for instance a measure of their wealth like GDP, with the hope to increase the probability to make the average and median parameters coincide.

Proposition 9 *Under Assumptions 4, 5 and 7, the process with the majority voting scheme has a biodiversity steady state which is Pareto optimal and asymptotically stable.*

Proof. The property that the steady state of the process is Pareto optimal is obvious. As for the stability property, to establish the proof it is sufficient to find a Lyapounov function. Let us denote $W(S, y_1, ..., y_n) = \sum_i NB^i(S, y_i)$ the utilitarian measure of welfare. Clearly the function $f(S, y_1, ..., y_n) = W(\hat{S}, \hat{y}_1, ..., \hat{y}_n) - W(S, y_1, ..., y_n)$, where $(\hat{S}, \hat{y}_1, ..., \hat{y}_n)$ is the utilitarian Pareto optimum, qualifies as a Lyapounov function. Indeed:

1. it is a continuous function with $f(\hat{S}, \hat{y}_1, ..., \hat{y}_n) = 0$,

2. along any outcome of the process, $f(S, y_1, ..., y_n) > 0$,
3. it is strictly decreasing along the process, at any point but the steady state.

■

This second process has two comparative advantages over the previous one. First, truthful behavior is a dominant strategy, which is the strongest incentive property one can obtain from a mechanism. Since agents are free from any strategic uncertainty when they devise their optimal behavior, the procedure could be also applied to a situation where countries do not know each other preferences. The second advantage is that there is no coordination problem any more. But those strengths come at a cost. First Assumption 7 is very demanding. If it does not hold, there is no guaranty that the process will converge any more: it may stop below the Pareto optimal level of biodiversity (a second best result). Furthermore, even when all the required assumptions hold, there is no guaranty that every country will see its utility increased along and at the steady state of the procedure. In some cases, the voting scheme could lead to changes which are harmful for some countries. This is the direct consequence of the sharing rule and the absence of any transfers between countries to correct for the inequal benefits from moving to a Pareto outcome.

4 Conclusion

How does the conclusions drawn from the two proposed processes compare with the conclusions from Barrett's repeated game argument? Barrett's main result is that when the gain from cooperation is large enough, cooperation cannot be sustained as a non cooperative outcome. Here on the contrary, such large gains can be implemented *via* the first process. Its main weakness is the potential coordination problem raised by the multiplicity of Nash equilibria that support a given Pareto optimum. The assumption of naive behaviors might also be viewed as another weakness, though some may argue that the assumption of super rational countries is an even worse alternative way to conceptualize behaviors. The coordination problem can be overcome when the process is qualified with a majority voting scheme (Section 3.3). Besides the resulting equilibrium is made of dominant strategies. Unfortunately, it has been shown that at the same time the property of individual rationality is lost, i.e. the process may be harmful for some countries. Besides, only under a traditional (and demanding) assumption of equality between average and median values of the marginal net benefits, does the process converge to a Pareto optimum. A challenging further research would be to find a way to discard the coordination issue of the first process, while preserving its other nice properties. This paper is a first step in that direction.

References

[1] Barrett S., 1994, "The Biodiversity Supergame", *Environmental and Resource Economics*, 4, 111-112.

[2] Bowen H., 1943,"The interpretation of voting in the allocation of economics resources", *Quarterly Journal of Economics*, Vol. 58, pp 27-48

[3] Champsaur P., J.-H. Drèze and C. Henry, 1977, "Stability theorems with economic applications", *Econometrica*, 45(2), 273-294.

[4] Chander P., and H. Tulkens, 1992, "Theoretical foundations of negotiations and cost sharing in transfrontier pollution problems", *European Economic Review*, 36, 388-398.

[5] Schoumaker F., 1979, "Strategic behaviour in a discrete-time procedure", Chap. 20 in Aggregation and Revelation of Preferences, Studies in Public Economics, vol. 2, 367-376.

[6] Green J. and J.J. Laffont, 1979, "Dynamic approaches", Ch. 14 in Incentives in Public Decision-Making, Studies in Public Economics, vol. 1, 249-258.

[7] Roberts J., 1979, "Incentives in Planning Procedures for the Provision of Public Goods", *Review of Economic Studies*, 46, 283-292.

[8] Tulkens H., 1978, "Dynamic processes for public goods. An institution-oriented survey", *Journal of Public Economics*, 9, 163-201.