Biodiversity conservation and carbon mitigation: two problems, one solution? Searching for answers using uncertainty and game theories.

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• **Resumo**

Esse artigo tem três objetivos complementares. Primeiro, enfatizar a relação entre a conservação da diversidade biológica e a redução dos gases causadores do "efeito estufa" por países em desenvolvimento. Segundo, mostrar utilizando a teoria da incerteza que a conservação da diversidade biológica não é economicamente ótima. Finalmente, através de um Modelo de Gerações Superpostas (OLG) que a conservação das espécies naturais com o objetivo de mitigar os efeitos das emissões de gases causadores do aquecimento global é ótima tertemporalmente. Como é amplamente sabido, o Protocolo de Kyoto não é, até o presente momento, eficiente para reduzir a emissão dos gases causadores do aquecimento global. O principal problema é que não há incentivos econômicos para que os países responsáveis pela maior parte das emissões cumpram as determinações do acordo.

Palavras-chave: diversidade biológica, aquecimento global, modelo de gerações superpostas.

Área de Classificação da ANPEC: Área 05 (Economia Regional e Economia Agrícola).

• **Abstract**

This paper has three complementary objectives. First, to emphasise the relationship between conservation of biological diversity and carbon mitigation in developing countries. Second, to show, using the uncertainty theory that the conservation of biological diversity is not economic viable. Finally, through an Overlapping Generations Model (OLG) to demonstrate that to conserve biological diversity with the objective of reducing emissions of greenhouse gases is optimal overtime. As is well known, the Kyoto Protocol is not, for the time being, efficient to reduce CO_2. The main problem lies upon the lack of economic incentives to motive main polluter countries to obey the Protocol rules.

Key words: biological diversity, global warming and overlapping generation model.

JEL Classification: Q2

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• Initial Considerations

There is a growing concern with the consequences of provoked climatic changes. Emissions of gases are originated from several human activities, many of them essential to the process of economic growth. Improvements of people well being also demands a larger use of environmental goods and services that could affect current and future generations. Transport of loads and people, increase of agriculture production, urbanisation, and industrialisation determine the level of standard of living of people and also the amount of emitted *per capita* greenhouse gases.

The discussion about the destruction of biological diversity has also been intense on ecological and economic grounds. Among the ecological reasons there are: the need to maintain the processes of natural evolution; to aid in the regulation of the physical-chemical balances of the biosphere; absorption and decomposition of pollutant organic, among others. The more important economic reasons are: the supply of nutritious products, raw material for the industry; development of the agricultural production; exploration of the biotechnology with the domain of the genetic manipulations; exploration of eco-tourism (LÉVEQUÊ, 1999).

Global warming and conservation of biological diversity are both subject of international conventions. The ultimate objective of the Climate Change Convention (CCC) is to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system[1]. The Convention on Biological Diversity (CBD) deals with international rights to have access, to use and to conserve the available genetic resources in the world. In spite of emphasising "the conservation and the sustainable use of the biological diversity for the present and future generations (ASSAD and PEREIRA, 1998, p.29), the CBD does not entering thoroughly in the related economic aspects (HURLBUT, 1994, p.2).

Some scholars, however, are sceptical in relation to the viability of implementation and to the effectiveness of both conventions. DORE, GUEVARA and NOGUEIRA (1999) pointed out some crucial questions about CCC[2], in particular lack of financial commitment and of enforcement

[1]Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (Article 2).

[2]Dore, Guevara and Nogueira (1999) listed the following problematic aspects related to the CCC and to the Kyoto Protocol (KP): a) they will have to rely on the existing Global Environmental Facility; there is NO additional money committed to reach the objectives of the Convention; to date the Clean Development Mechanism (CDM) is just an empty gesture, without any commitment for any Annex 2 nation; b) the Secretariat has NO funds to adjustment for developing countries; no developing country will have any incentive to sign on to KP; c) there are no penalties for no-compliance with KP; there is no reason to suppose that the KP targets will be met by the Annex 1 countries, and the responsibilities of Annex 2 countries are not spelled out in KP; there is no enforcement mechanism and from the legal point of view KP is *indistinguishable* from the CCC, just as the targets of the Convention were no met and there were no penalties, KP targets are in essence voluntary and therefore *indistinguishable from those of the CCC*; d)

mechanisms to reach its objectives. Similar criticisms may be made to the CBD. Result of a long debate rotated around conflicting positions between developed (PD) and developing (PED) countries, the CDB emphasises the need of inventory by signatory countries of their biological resources, in order to protect their threatened species. That would allow them to exchange information and genetic resources with the purpose of sharing research information, profits and technological know how. Thus, PED (biodiversity deposits) would give up their biological resources in exchange for technology, provided mainly by PD.

Nevertheless, both conventions will play a crucial role on future discussion between PED and PD on environmental matters. Brazil, in particular, has the largest area under tropical forest in the whole world, with significant biological diversity. However, Brazil has also the highest global annual rate of deforestation. We agree with FEARNSIDE (1999) that any measure able to reduce the rate of deforestation will represent a huge contribution to reduce greenhouse gas emissions and to conserve biological diversity. This paper contributes in identifying basic characteristics of a measure like that, using uncertainty and game theories. In the next section, we present a uncertainty model to analyse issues affecting biodiversity conservation. It is followed by an game theoretic OLG model dealing with key aspects of cooperation toward global warming mitigation. Finally, consequences of our results for policy design are discussed in the final section.

- **Safe Minimum Standard and the CBD: a new game proposed.**

Biodiversity is, definitively, of economic interest. The importance of biological diversity may be analysed at a microeconomic level, in which those resources are used as raw materials for economic activities, especially in medicine related industries [see SIMPSON, SEDJO & REID (1996); RAUSSER & SMALL (2000); BARRETT & LYBERT (2000)], or as a final product (eco-tourism). There are also models based upon the theory of finance, that would seek to explore the value of option to biodiversity (POLASKY, SOLOW & BROADUS, 1993). Another form of considering the economic importance of biodiversity is at the macroeconomic level. There are models discussing the importance of the biodiversity to the international trade (CABO, 1999) or the interactions and conflicts between conservation and development (NORGAARD, 1987; NEUMAYER, 1998). There are also models studying the theme of international co-operation as a requisite for conservation, using game theory.

As a matter of fact, game theory has been widely used in studies dealing with conservation of biological diversity. In one of these studies, LÉVEQUÊ (1999) argues that the principle of equality among generations is an ethical reason to conserve biodiversity. That principle determines that the next generation is entitled to receive the planet in the same way that the current generation received it, in terms of natural resources. TISDELL (1999) agrees, considering

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KP does not match the equity provisions of other in international agreements, like the Montreal Protocol for CFCs; e) it does nothing to implement the equity provisions of the CCC either; f) from the point of view of equitable implementation of a global climate policy that is designed to slow down global warming, the only conceptual innovation in KP is the CDM; but money has yet to be provided for it; and g) KP is therefore nothing more than a gesture of good will.

the principle of equality as a sustainability criterion, being fundamental in maintaining the economy.

The Convention on Biological Diversity (CBD) points out that we should conserve the biological diversity to protect humanity of eventual natural disasters. These disasters can be avoided and/or their impacts minimised with the existence of biological diversity. There are still the ethical and existential reasons. CBD arguments resemble the theory of Safe Minimum Standard (SMS), formulated by CIRIACY-WANTRUP (1968). His basic argument is to guarantee the conservation while the costs are socially acceptable, not mattering potential value or revenue derived from the projects. SMS doesn't specify limits to social costs of conservation. In this context, the use of biodiversity resources should be limited to essential activities. Development projects should be discarded, unless it is considered to be vital for society well being.

The basic argument for following a SMS strategy is that potentials social costs due to the destruction of biodiversity stocks can be much larger than any benefit from development projects. Biodiversity destruction may be irreversible, while development projects can be reallocated or modified without larger damages. This argument is controversial. If it is true that several lethal diseases affect humanity, it is also true one does not know if cure for this disease could be found in a given organism. However, it may be found in a particular plant and what would be the social cost if this plant were extinguished? It is, therefore, extremely difficult to verify empirically the validity of SMS formulation.

Nevertheless, many economists have accepted the challenge of Ciriacy-Wantrup's ideas and have tried to validate the SMS. A landmark in this direction is the study by BISHOP (1978), who uses a game theory model[3]. His model describes a static game between *society* and *nature*, called "insurance game", in which the rule of decision is to maximize the usefulness for *society*, given the actions of *nature*. The former is confronted with a choice between to conserve a certain area or to implement a development project that will destroy local biodiversity. *Nature* then determines if there is or not the outbreak of a disease, which cure can be found with certainty in a specie existing in the area.

Bishop's results corroborated the insights by Ciriacy-Wantrup. In 1991, however, READY and BISHOP (1991) re-analysed the theme, formulating two types of games. Their results suggested two opposite and conflicting strategies of conservation: one recommending a maximum and the other a minimum of conservation. Since then SMS lost some of its theoretical appeal. Results by Ready and Bishop were confronted by PALMINI (1999). He argues that the two games built by READY & BISHOP (1991) were, actually, sub-games belonging to a more complex structure. Solving a dynamic game[4], Palmini found

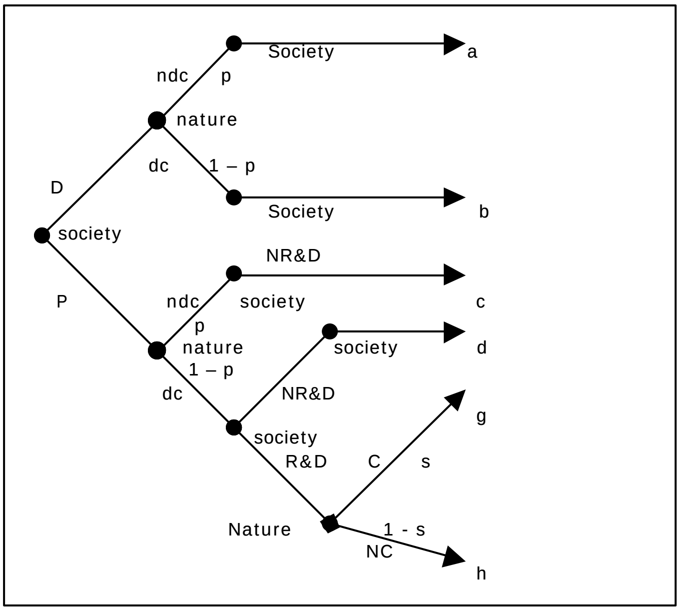
[3]It is our opinion that there is a misunderstanding in this formulation. As it is a situation of decision considering actions of nature, that is not a rational opponent, it is not a case for a game, but of a choice situation under risk or uncertainty.
[4]The problem with this model, that also appears in BISHOP (1978) and READY & BISHOP (1991), is the situation defined, the interaction society-nature, as a game. We agree with MYERSON (1991) in defining a

evidences that would justify SMS. In other words, he pointed out that the best strategy in the presence of uncertainty is to guarantee the maximum conservation level.

In models built to justify the SMS, players are “society” and “nature”. Actions of society are defined into preserving or not the biological diversity, given that the state of nature in the future is not known. Actions by “nature”, therefore, don't obey a rational and intelligent behaviour. They are, of course, random. The maximum one can do is to analyse probabilities based upon information of previous situations and to do forecasts of the future. Then it can be concluded that the model developed by PALMINI (1999) is not a game but actually a model of choice involving risk.

Palmini’s model describes a situation where there is a rational agent making choices under risk and/or uncertainty. In a situation like this, the game theory approach is not the most appropriate. The best way to formalise this situation is to apply the *expected utility property*[5]. Under a situation of risk and uncertainty society has to choose between “development” and “conservation”. This choice can be illustrated in Figure I:

Figure I
The Interaction Between Society and Nature



Source: Palmini (1999) with adaptation by authors.

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game as: " A conflict situation and cooperation among [two or more] rational and intelligent players” (MYERSON, 1991, pp. 1).

[5]It is assumed that utility functions respect the three postulates necessary to apply the expected utility property: completeness, continuity and monotocity. For a detailed description of these properties see HARSANYI, 1986)

Where:

D represents the choice of *development*;

P represents the choice of *conservation*;

dc e *ndc* are actions of nature, represented by the outbreak or not of a new disease, respectively;

R&D e *NR&D* are choices by society between search or not for the cure of the new disease through research and development;

C e *NC* represent actions of nature, in the sense that the cure will or will not be possible through the efforts of society;

p e *s* represents probabilities of happening each state of nature in each one of these situations;

a, b, c, d, g e *h* represents the payoffs.

The options to society, in a risky situation, are:

$D = \{a, p; b, (1 – p)\}$[6] (1)

$P = \{c, p; X, (1 – p)\}$ (2)

where $X = \{g, s; h, (1 – s)\}$ (3)

therefore $P = \{c, p; g, (1 – p)s; h, (1 – p)(1 – s)\}$ (2')

Assuming uncertainty, options to society are given by:

$D' = \{a|e; b|\bar{e}\}$[7] (4)

$P' = \{c|e; X'|\bar{e}\}$ (5)

$X'= \{g|f; h|\bar{f}\}$ (6)

$\Rightarrow P' = \{c|ef; g|\bar{e}f; c|e\bar{f}; h|\bar{e}\bar{f}\} = \{c|e; g|\bar{e}f; h|\bar{e}\bar{f}\}$ (5')

In this model **p** is the probability that a new disease will appear and that the biodiversity is necessary somehow to combat it. It is reasonable to suppose that this probability is not know; that is, society can only form opinion about the case. The probability of finding cure for this disease obeys the same logic, because we do not know which organism has the possibility of cure and we do

[6]It can be read: in choosing development, society receives **a** with probability **p** and **b** with probability **(1 – p)**.

[7]It can be read: in choosing development, society receives **a** if event **e** occurs and **b** if event $\bar{e}$ occurs.

not know whether the scientific research will be effective in finding the cure. This is, therefore, a problem of maximising expected utility under uncertainty. Applying the property of expected utility to equations (4) and (5`), we have:

$$U(D') = U(a|e; b|\bar{e}) = p^eU(a) = (1 - p^e)U(b) \quad (8)$$

$$U(P') = U(c|e; g|\bar{e} f; h|\bar{e}\ \bar{f}) = p^eU(c) + (1 - p^e)s^eU(g) + (1 - p^e)(1 - s^e)U(h) \quad (9)$$

Where p^e e s^e are, respectively, subjective probabilities attribute by society to events "no out break of disease" (ndc) e "development of cure" (C). To conserve will be the best strategy if:

$$U(P') \geq U(D') \quad (10)$$

PALMINI (1999) defines values relevant to the problem as:

- B^d: benefit to society due to the development project;
- $B^p{}_c$: immediate benefit of conservation to society (may represent the existence value of conservation);
- $B^p{}_f$: potential future benefit, after the outbreak of a disease and in the case that cure is found;
- L: costs of research, development and application of the new drug;
- R: Costs of research and development, in the case the cure is not found (that is, *sunk costs*).

A few hypotheses must be made to deal with the model:

1. $B^d > B^p{}_c$, to justify society doubts between to conserve and to develop;
2. $B^p{}_f >> L$, disease, if it becomes a reality, will bring high negative consequences to society;
3. L > R, a consequence of R representing a frustrated option.

In this context, the payoffs of Figure I are:

- $a = B^d$
- $b = B^d - B^p{}_f$
- $c = B^p{}_c$
- $d = B^p{}_c - B^p{}_f$[8]
- $g = B^p{}_c - L$
- $h = B^p{}_c - B^p{}_f - R$

Taking these values as utilities for society in each situation[9] and applying equations (8) and (9):

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[8]The *payoff* **d**, that corresponds to a, preservation → disease → research does not take place, is strictly worse than *payoff* **g** and can, therefore, be eliminated.

[9]We follow here the description by PALMINI (1999), as shown in Figure 1. The change is restricted to the resolution procedure.

$$U(D') = p^e B^d + (1 - p^e)(B^d - B^p{}_f) = B^d - B^p{}_f(1 - p^e) \quad (11)$$

$$U(P') = p^e B^p{}_c + (1 - p^e)s^e(B^p{}_c - L) + (1 - p^e) (1 - s^e)(B^p{}_c - B^p{}_f - R) =$$
$$= s^e(B^p{}_f - L + R) + p^e(B^p{}_f + R) + p^e s^e(L - B^p{}_f - R) \quad (12)$$

Replacing in (10):

$$s^e(B^p{}_f - L + R) + p^e(B^p{}_f + R) + p^e s^e(L - B^p{}_f - R) \geq B^d - B^p{}_f(1 - p^e)$$

Simplifying:

$$s^e(B^p{}_f - L + R) + p^e R \geq B^d - B^p{}_f(1 - p^e) + p^e s^e(B^p{}_f + R - L) \quad (13)$$

Re-writing:

$$B_f^p \geq \left(\frac{1 - s^e}{s^e}\right)R + \left(\frac{1}{s^e(1 - p^e)}\right)(B^d - B_c^p) \quad (14)$$

Note that the value of this inequality depends basically upon the probabilities of the disease outbreak, $(1 - p^e)$, and of finding the cure, (s^e). In the "best situation"[10] ($p^e = 0$ e $s^e = 1$) the condition to guarantee conservation is $B^p{}_f + B^p{}_c \geq B^d$, that is, social benefits of conservation must be higher than social costs of conservation. This is exactly the decision rule proposed by CIRIACY-WANTRUP (1968), the SMS. Any case social benefits must be higher than social costs represented by the opportunity costs of giving up development, due to uncertainty. In the limit ($p^e \to 1$ e $s^e \to 0$)[11] future benefits of conservation must achieve a very high value to justify the conservation strategy. Table I below shows some results.

Table I: Results of the utility maximisation rule[12]

Probabilities	Necessary condition for conservation
$p^e = 0$ e $s^e = 1$	$B^p{}_f + B^p{}_c \geq B^d$
$p^e = 0{,}2$ e $s^e = 0{,}4$	$B^p{}_f \geq 3{,}125(B^d - B^p{}_c) + 1{,}5R$
$p^e = 0{,}5$ e $s^e = 0{,}5$	$B^p{}_f \geq 4(B^d - B^p{}_c) + R$
$p^e = 0{,}6$ e $s^e = 0{,}3$	$B^p{}_f \geq 8{,}34(B^d - B^p{}_c) + 2{,}34R$
$p^e = 0{,}8$ e $s^e = 0{,}8$	$B^p{}_f \geq 6{,}25(B^d - B^p{}_c) + 0{,}25R$
$p^e \to 1$ e $s^e \to 0$[13]	$B^p{}_f \geq 10^{20}(B^d - B^p{}_c) + 9{,}99x10^{10}R$

Source: Estimate by the authors.

The *Safe Minimum Standard* of CIRIACY WANTRUP (1968) continues without a concrete theoretical justification. Society, even believing that biodiversity may

[10]In the sense that, intuitively, the preservation should be the best alternative.
[11]When $p^e = 1$ e $s^e = 0$ the result is not determined.
[12]In a previous version of this paper we also applied a rule of minimising regret, as proposed by Palmini (1999). Using the rule proposed by Loomes & Sugden (1982) to utility with regret, we obtained "worse" results than those obtained trough the utility maximization rule, in the sense that the application of SMS is never optimal.
[13]In a approximation with ten decimal points.

be necessary in the future, would rather receiving actual benefits from development in the present than potential benefits of biological diversity. This behaviour is justified due to existence of additional costs to use the biological diversity resources. In this context, one may argument that the CBD is not rational from an economic point of view. However, as it was signed there is no sense in discussing to preserve or not. Signatory countries, as Brazil, must look for cooperation and adjust their social needs to achieve conservation.

A comparative static analysis of this model reveals na interesting conclusion. An usual hypothesis is that present benefits of conservation are always smaller than development benefits. From our results we may argue that as benefits from conservation increase it become easier to make conservation economically attractive. In order to increase these net benefits of conservation one has either to reduce costs or to increase benefits of conservation projects. A possible strategy to increase benefits is to consider the value of the Amazon rainforest (the world's biggest biodiversity site) as an alternative to mitigate effects of CO_2 emissions. In other words, to include the Amazon forest in the Kyoto protocol objectives may transform the CBD in an economic viable institution.

Nevertheless, still remains the intergeneration problem. That is, conflicting decisions among different generations of individuals may make conserbationa a not viable option. To deal theoretically with this problem one can consider a model where the agents live infinitely and inter-temporal aspects are lost, or to insert several generations of people, analysing the interactions among them. In that type of analysis the most used tool is the overlapping generation model (OLG). Many analyses have already been made using OLG on environmental issues. As far as conservation of biodiversity is concerned, VOM AMSBERG (1995) considered the existence of incomplete markets as responsible for a politics of inefficient conservation[14]. The inefficiency derives from the fact that the risk faced by the current generation what determines the amount of available biodiversity for the future generation. The conservation decision of today is made under uncertainty and the decision of tomorrow is just an adaptation to the conditions imposed by the current generation. In that context, it can have a larger risk for the next generation, that will not be able to avoid it[15].

Through the resolution of his model, VOM AMSBERG (1995) concludes that in the presence of that market failure, the current generation will invest less in conservation than social necessary, because the risk she confronts is smaller than the risk that will be confronted by the future generation, Similarly, if the risk today is larger than the risk of the next generation, there will be over-investment in conservation. It is relevant to emphasise that VOM AMSBERG'S model just considers the option value of biodiversity, as proposed by ARROW & FISHER (1974). There is no possibility of altruism, nor of existence value. Another

[14]The author defines an incomplete market in an inter-temporal context as a market where there are two generations. The future generation cannot accomplish contracts. The current generation interacts with the one that has not been born and, rationally, it doesn't worry about the future generation.

[15]In the sense that the bad state of nature today, as in the case of emergence of some incurable disease, it will become worse tomorrow.

important factor is that it would be necessary to have a measure of the extinction risk, what is not easy.

- **OLG Model and Global Warming**

A discussion of the critical determinants likely to influence overall *costs* and *benefits* of mitigating greenhouse gases (GHG) emissions have been present in many existing empirical studies. In the *cost side*, three aspects received attention: (i) different concepts of mitigating costs that have been used in the models; (ii) selection of base-lines and policy strategies and (iii) differences among models. In the *benefit side,* marginal climate change damage avoided is equal to the marginal climate change benefits of emission control. However, the benefits of abatement will not be limited to reduce climate change costs alone.

Our model describes relationships among overlapping generations (OLG) in the decision to conserve a certain natural area, believed to be capable to mitigate global warming effects. The central idea is to extend the model formulated by VON AMSBERG (1995), with the purpose of capturing the resulting effect of the non execution of a contract by the future generation. In this context, instead of only two periods, as in Von Amsberg's paper, a third period is considered aiming to observe the result of a possible retaliation by the initial generation.

Therefore there is three generations **j** (j = 1, 2, 3). The generation j = 1 lives in periods t = 1 and t = 2. Generation j = 2 lives in periods t = 2 and t = 3. Finally, the generation j = 3 lives just in the period t = 3. Consumption of each generation (from which utility will be derived) is distributed in each period that this generation is alive. In this situation, each generation will receive an initial endowment and in the case of generations 1 and 2, this endowment should be distributed among both periods they will be alive. Therefore, for the first two generations, their utilities will be determined by consumption in the first period and by a part of the consumption during the second period. However, all the endowment will be consumed by the end of both periods.

Generation 1 receives an initial endowment E1. From this endowment she will have to remove consumption of periods t = 1 and t = 2. A discount factor for inter-temporal consumption will not be considered. The Generation 1 will still have to decide if conserves a certain area L, that will be deduced from its endowment. The conservation of this area is justified by the role in reducing global warming impacts, in the case global warming really happens. The Generation 1 hopes to obtain from Generation 2 a payment for the conservation of area L in t = 2. This payment refers to the cost of conservation incurred by Generation 1.

In other words, Generation 1reduced consumption the first period and it waits to be reimbursed in the following period. After all, Generation 2 will be the largest beneficiary with the conservation, if global warming happens. In case j = 2 decide not to pay, Generation 1 can adopt a retaliatory strategy, consuming a part of the area L (it will consume ½L) in t = 2. In so doing, the next generations will receive only a part of the benefits derived from conservation. It should be observed that Generation 1 will incur in a loss derived from not consuming L in period 1 and doing it in period 2.

Notice that if global warming is observed in t = 2, the Generation 1 will also suffer its effects in case it has not conserved the area L. Losses due to the effects of global warming is given by G. However, effects upon Generation 1 only affects its utility in one consumption period, while for Generation 2 will suffer effects in both periods it is alive. The same happens with Generation 3 that only lives and consumes in period t = 3.

It is obvious that Generation 2 will have to make two decisions. First, it should decide if it pays or not Generation 1 for the conservation. When making this decision, j = 2 already observed the state of nature in the period t = 2, but not in t = 3. Consequently, we have two states of nature. The state A, good state, where global warming does not with probability p, and the state B, bad state, in which the global warming takes place, with probability 1 - p. It is assumed at this point that if state B is observed in t = 2, unfortunately it will also be observed in t = 3. (if we had more periods, the occurrence of the global warming in any period would be automatic so that B always happened in the following periods)[16].

The second decision of Generation 2 concerns the conservation or not of the protected area. An important point derived from the discussion above is that if the state B be maintained in t = 2, then the option of the generation 2 will always be in favour of conservation, even if it is only the portion not consumed by Generation 1 in retaliation to the non payment by Generation 2. As a matter of fact, the state B in period t will induce the choice of conservation by following generations. It is easy to explain why. If we do not have more uncertainty in relation to the occurrence of global warming, conservation insuring the neutralisation of its effects will always be better to conserve after the start given by B.

But what is in fact important is to analyse if it the correct decision to conserve when there is the uncertainty in relation to the state of nature in the following period. Then, we need to know how certain we are about the utility of each generation. As we have seen previously, Generation 1 derived utility from consumption in periods 1 and 2. If Generation 1 chooses not preserving, its total consumption in both periods is E1. If state B occurs it will represent a loss represented by G. If Generation 1 chooses to preserve, its consumption in both periods will be E1 - L, where L is the conserved area. With conservation, global warming impacts will be neutralised in the second period.

The utility of Generation 1 will still depend upon the choice of Generation 2 in paying or not for the conservation of area L. In the case of no payment, Generation 1 will still be able to consume the equivalent to ½L in period t = 2 (necessary hypothesis otherwise it would consume everything and would not have any loss; the partial payment softens the loss but it doesn't eliminate it). If

[16]On the other hand, the occurrence in t =2 does not mean that it will also necessarily occur in t = 3. In this period, the occurrence probabilities of states A and B are represented by s and 1 - s, respectively. Observe that these probabilities can be interpreted as the concept of subjective probability.

the decision is to not conserve, it represents na option for development that will also be enjoyed by next generations, supplying an additional utility of D for all three generations. It is supposed that G = D; in other words, the occurrence of global warming eliminates the gains of utility obtained with the choice of development.

The utility for Generation 2 will be derived from its consumption in periods 2 and 3. This generation also receives an initial endowment E2. This endowment besides being divided among periods in which the generation lives, it should pay to the Generation 1 for the conservation of area L, if it decides to do so. Thus, if Generation 2 decides to make the payment, its total consumption in periods 1 and 2 will be E2 - L, respectively. If it decides not to pay, it will consume E2. However, this consumption will be affected by the occurrence of global warming effects. Therefore, the utility of Generation 2 will be reduced during periods the state B is observed. In other words, if the global warming happens in periods 2 and 3, the utility of Generation 2 will be reduced in both periods by the factor G.

We suppose here that G = 2L. That is, the lost utility due to the occurrence of global warming will be twice what it wins with the destruction, or the consumption, of area L. Observe that if Generation 2 does not pay for the conservation of L, Generation 1 will consume ½L in the period 2. Therefore, Generation 2 will have to decide if it conserves or not the area ½L for the following period. It is also important to notice that this area will offer a protection proportional to its size against global warming. Therefore, global warming is observed, its effect will be ½G.

Finally, the utility of Generation 3 will only be given by its consumption in the period t = 3. Generation 3 can be affected by the state B if this happens without protection or with just partial protection. However, this generation does not have any decision power, nor capacity of retaliation. It is important to observe that the Generation 2 cannot demand a payment from Generation 3 because it is not possible to apply a retaliation strategy because the game finishes in the period 3. Consequently, if Generation 2 pay for the conservation, it has already paid the costs of conservation. These cannot be postponed *ad infinitum*.

A hypothesis to be added before the resolution of the game is that if together Generations 1 and 2 are indifferent between conserving or not, they conserve. In the same way, if the Generation 2 is indifferent between paying or not, she pays.

We will analyse utility for each generation of each situation.

1.1) Generation 1 doesn't conserve
2.1) With global warming in t = 2 (what means global warming in t = 3)

$$\text{(k)} \quad \begin{aligned} U_1 &= E_1 - G + D \\ U_2 &= E_2 - 2G + D \\ U_3 &= E_3 - G + D \end{aligned}$$

2.2) Without global warming in t = 2, but with global warming in t = 3

(b)
$$U_1 = E_1 + D$$
$$U_2 = E_2 - G + D$$
$$U_3 = E_3 - G + D$$

2.3) Without global warming in t = 2 and t = 3

(a)
$$U_1 = E_1 + D$$
$$U_2 = E_2 + D$$
$$U_3 = E_3 + D$$

1.2) Generation 1 conserves
2.1) With global warming in t = 2 (and therefore in t = 3)
3.1) Generation 2 pays for the conservation
4.1) Generation 2 also conserves

(l)
$$U_1 = E_1 - L + L = E_1$$
$$U_2 = E_2 - L$$
$$U_3 = E_3$$

3.2) Generation 2 doesn't pay for the conservation
4.1) Generation 2 conserves what remained

(m)
$$U_1 = E_1 - L + ½L = E_1 - ½L$$
$$U_2 = E_2 - ½G$$
$$U_3 = E_3 - ½G$$

2.2) Without global warming in t = 2, but with Global Warming in t = 3
3.1) Generation 2 pays for the conservation
4.1) Generation 2 also conserves

(g)
$$U_1 = E_1 - L + L = E_1$$
$$U_2 = E_2 - L$$
$$U_3 = E_3$$

4.2) Generation 2 doesn't conserve

(h)
$$U_1 = E_1 - L + L = E_1$$
$$U_2 = E_2 - L + L - G = E_2 - G$$
$$U_3 = E_3 - G$$

3.2) Generation 2 doesn't pay for the conservation
4.1) Generation 2 conserves what remained

(i)
$$U_1 = E_1 - L + ½L = E_1 - ½L$$
$$U_2 = E_2 - ½G - ½L$$
$$U_3 = E_3 - ½G$$

Observation: In U_2, ½L represents the cost of conservation of the remaining area that should be arched by the generation 2.

4.2) Generation 2 doesn't conserve

$$U_1 = E_1 - L + \tfrac{1}{2}L = E_1 - \tfrac{1}{2}L$$
(j) $$U_2 = E_2 + \tfrac{1}{2}L - G$$
$$U_3 = E_3 - G$$

2.3) Without global warming in t = 2 and t = 3
3.1) Generation 2 pays for the conservation
4.1) Generation 2 also conserves

$$U_1 = E_1 - L + L = E_1$$
(e) $$U_2 = E_2 - L$$
$$U_3 = E_3$$

4.2) Generation 2 doesn't conserve

$$U_1 = E_1 - L + L = E_1$$
(f) $$U_2 = E_2 - L + L = E_2$$
$$U_3 = E_3$$

3.2) Generation 2 doesn't pay for the conservation
4.1) Generation 2 conserves what remained

$$U_1 = E_1 - L + \tfrac{1}{2}L = E_1 - \tfrac{1}{2}L$$
(c) $$U_2 = E_2 - \tfrac{1}{2}L$$
$$U_3 = E_3$$

4.2) Generation 2 doesn't conserve

$$U_1 = E_1 - L + \tfrac{1}{2}L = E_1 - \tfrac{1}{2}L$$
(d) $$U_2 = E_2 + \tfrac{1}{2}L$$
$$U_3 = E_3$$

Resolution of the Game (to see extensive form):

1) Subgame in t4: Generation 2 makes two choices:

$$U(Pay - Pr) = s(E_2 - L) + (1 - s)(E_2 - L) = E_2 - L$$
$$U(Pay - DPr) = s E_2 + (1 - s)(E_2 - G) = E_2 - (1 - s)G$$

$$U(DPay - Pr) = s(E_2 - \tfrac{1}{2}L) + (1 - s)(E_2 - \tfrac{1}{2}G - \tfrac{1}{2}L) = E_2 - \tfrac{1}{2}L - (1 - s)\tfrac{1}{2}G$$
$$U(DPay - DPr) = s(E_2 + \tfrac{1}{2}L) + (1 - s)(E_2 + \tfrac{1}{2}L - G) = E_2 + \tfrac{1}{2}L - (1 - s)G$$

Conclusion: U(Pay - Pr)> U(DPay - Pr) if (1 - *s*) > ¾, reminding that (1 - *s*) it is the probability of occurrence of the global warming in the period t = 3, in case it has not happened in the period t = 2.

2) Subgame in t5: Generation 2 chooses between to pay or not to pay

U(Pay) = E_2 - L
U(DPay) = E_2 - ½G

Conclusion: For hypothesis, G = 2L. Therefore, Generation 2 will be indifferent between to pay or not to pay. Also for hypothesis, it is supposed that it will pay.

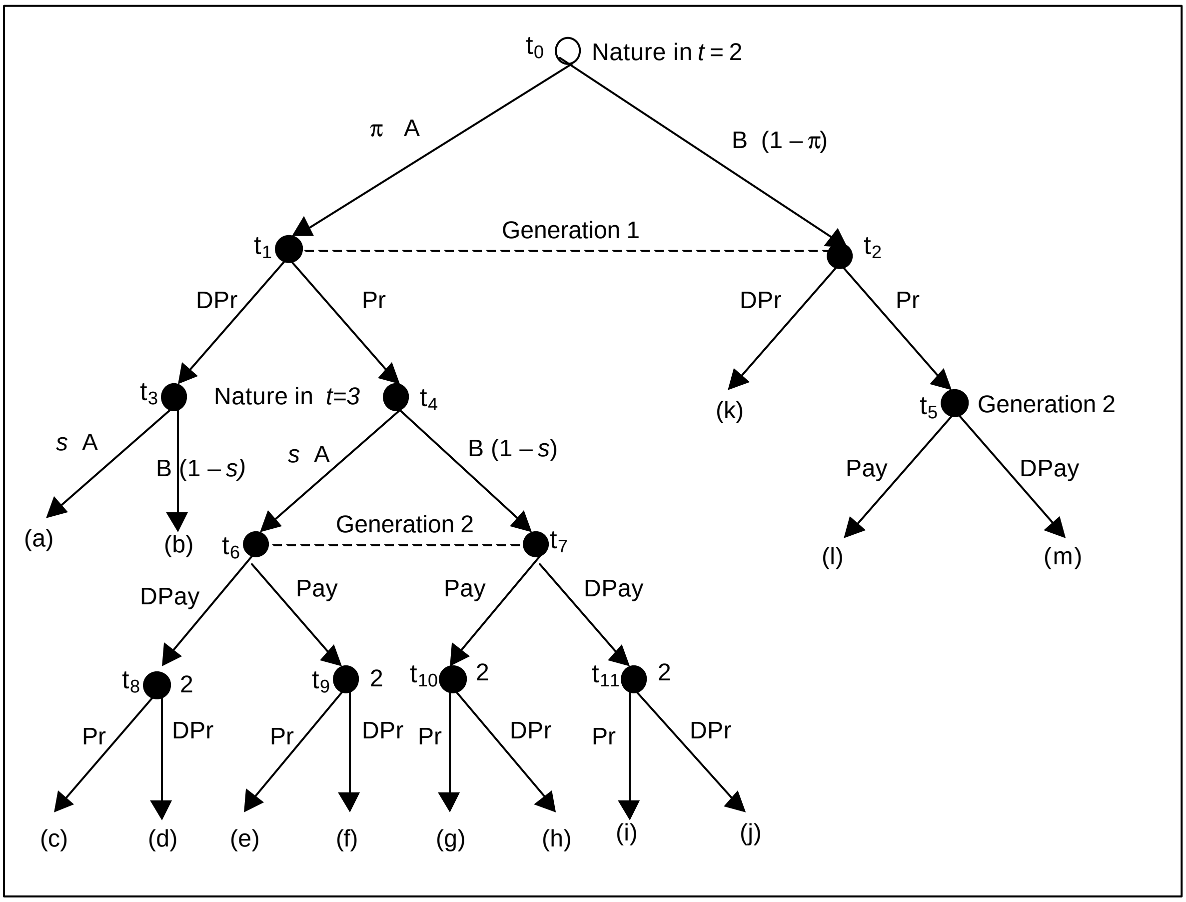
3) The whole game: Generation 1 chooses between to conserve or not to conserve

U(Pr) = E_1
U(DPr) = E_1 + D - (1 - *p*)G

Conclusion: For hypothesis, D = G. Therefore, U(P)> (ÑP), and Generation 1 will conserve.

Figure II

Overlapping Generation Model and Global Warming



Pr → Conserve
DPr → Don't Conserve
Pay → Generation 2 pay for generation 1
DPay → Generation 2 doesn't pay for generation 1

- **Results and their Consequences**

In our first model, proposed to analyse the Safe Minimum Standard (SMS) strategy and its consequences for the CBD, it was possible to show that SMS continues lacking a concrete theoretical justification. When modelling the situation as a choice involving uncertainty, the conclusion is that society, even believing that biodiversity can be necessary in the future, it prefers current benefits of development than potential benefits derived from the maintenance of biological diversity. This result is justified by the existence of additional costs if someone wants to use biological diversity resources, as it was shown in Table I.

Another important result from our first model is the magnitude of the present benefits of conservation. It was assumed that those benefits were always smaller than the benefits of the development. Analysing our results it can be noticed that if we alter that relation it would become much easier to guarantee conservation. The question, then, becomes: how to increase present benefits of conservation? Or, putting in another way: how to decrease social costs of conservation? The solution is to turn conservation projects into self-financed activities.

Our second model was an overlapping generation model (OLG), used with the purpose of capturing the possibility to settle down a contract among generations. Simulating a contract like this would help to understand how we can motivate the current generation to conserve biological diversity aiming to mitigate global warming effects in the future. Our central idea was to extend Von Amsberg's model of 1995 in order to allow a retaliation strategy by the current generation against a future generation that does not follow what is established in the contract. In other words, the future generation does not want to share costs of conservation with the present generation.

Although some of our hypotheses can be considered very restrictive, they seem to be plausible. Solving the model, our conclusions indicate the conservation of biological diversity is justified in a situation in which there is a high probability of occurrence of global warming effects. is elevated (in this case if the probability of occurrence of Global Warming in the period 2 goes larger than 50% and in the period 3 of 75%, in case it has not happened Global Warming in the period 2). it should be observed although for the generation 2, the best choice is to execute the agreement and also to continue preserving so that one doesn't see harmed by the effects of Global Warming.

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