North-south unconditional transfers and the protection of biodiversity

Very preliminary draft. Do not quote.

Stéphanie Aulong*, Charles Figuières†, Sophie Thoyer‡.

September 7, 2005

Abstract

Biodiversity produces various types of benefits, some of them have global public good characteristics – they benefit all nations without exclusion and without rivalry– while others are regional inputs in the production functions of neighbouring countries. The purpose of this paper is to explore whether international income transfers can improve the global level of biodiversity and global social welfare. Southern countries are endowded with natural capital in the form of unspoilt biodiversity-rich land. They allocate optimally land and capital to two competing productive activities, agriculture et tourism. When transfers are organized from a northern biodiversity-poor country to southern biodiversity-rich countries, we show that Warr's neutrality theorem collapses except under restrictive hypothesis concerning the characteristics of the tourism and agricultural production functions. We also demonstrate that Pareto-improvements can be obtained even with reductions in the level of biodiversity.

KEYWORDS: Biodiversity, agriculture, tourism, north-south income transfers, public good, neutrality theorem.
JEL: Q10, Q57, Q58, H23, H41.

1 Introduction

Biodiversity conservation produces benefits which have a global public good dimension: they are non rival and non excludable at the international level.

*Service Eau - Economie, BRGM - 1039, rue de Pinville - 34000 Montpellier - France. Email: s.aulong@brgm.fr

†UMR LAMETA, 2 place Viala. 34060 Montpelier cedex 01. Montpellier - France. Email: figuiere@ensam.inra.fr. Corresponding author.

‡UMR LAMETA, 2 place Viala. 34060 Montpelier cedex 01. Montpellier - France. Email: thoyer@ensam.inra.fr.

Countries have therefore engaged into coordinated policies in order to improve it, within the framework of the Convention on Biological Diversity (CBD). However, the impact of the CBD on biodiversity is relatively limited, since it rests mostly on voluntary commitments made by signatory parties, with neither reliable means of control nor credible sanctions. One alternative solution is to investigate more thoroughly the effectiveness of international redistributive policies on the global level of biodiversity and on global welfare.

At first sight, this might appear as a surprising suggestion, for redistributive policies are generally designed to achieve equity goals, rather than efficiency or biodiversity conservation. Nethertheless, at least at a conceptual level, there are several interests to go through this exercise. In a context of environmental externalities like biodiversity it is generally not possible to separate out efficiency and equity goals: the Second Welfare Theorem does not hold here, which means that lump sum transfers may have an effect on social efficiency. But would they modify behaviors in the right direction? In the affirmative, they could be considered a simple and less costly instrument, in terms of transaction costs, that deserves further attention. Compared to more sophisticated incentive mechanisms, lump sum transfers do not have to cope with informational obstacles, nor do they have to face monitoring and compliance issues, since they are unconditional.

Actually, because of the public good nature of biodiversity, the theoretical literature suggests that such transfers may have no effect at all, neither on the level of biodiversity, nor on welfare. Indeed, Warr (1983) has demonstrated that the private provision of a public good is unaffected by a marginal redistribution of income between contributors, despite differences in their marginal propensities to contribute to the public good. In other words, an international policy which would induce some higher-income countries to contribute to a multilateral fund with the view to transfer revenues to lower-income countries would not improve the quantity of global public good supplied. The reason is that donor countries would then reduce their voluntary contribution to the public good to the amount of their lost income and would rely instead on contributions made by others. This phenomenon of "crowding out" is known as the "neutrality" theorem: redistributive policies amongst voluntary contributors are useless[1]. However, this result only holds for a public good whose technology of production is purely additive: each units contributed to the public good adds identically and cumulatively to the overall level of public good.

The objective of the paper is to revisit the Warr's "neutrality" theorem when the public good under consideration is biodiversity. A first challenge is to imagine a conceptual framework that captures important specific dimensions of the problem. From the many dimensions of biodiversity, we single out three. We first argue that biodiversity generates in fact two types of public

[1] Warr's demonstration holds for marginal transfers between agents who remain contributors after the change. It has been extended in Bergstrom et al (1986) and Cornes and Sandler (1985) who have been able to identify how large transfers can be before they change the set of contributors and do have an effect. Itaya et al (1999) offer an analysis of such large and non neutral transfers.

benefits: regional benefits associated with ecosystem services, which have the characteristics of regional public goods shared by several neighbour countries; and global benefits associated with the option value of the gene pool preserved. We then define two types of countries: ecosystem-rich countries can contribute to biodiversity conservation by preserving their natural ecosystems for tourism activities instead of converting them for higher local return activities (i.e.: agriculture); ecosystem-poor countries cannot preserve biodiversity "at home" and cannot therefore enjoy the local benefits of biodiversity but they can contribute financially to improve the global dimension of biodiversity conservation (i.e. by financing more research on biotechnologies). Finally, we assume that biodiversity is both a local input - when it is used in the tourism production function of ecosystem-rich countries - and a global public good which is an argument of the utility function of all countries. The aggregation function of countries' contributions to biodiversity conservation is therefore more complex than in Warr's generic model, which assumes additivity. Nor does it fall into the typology initially established by Hirshleifer (1983) and Cornes and Sandler (1984) who distinguish the *weakest link* and the *best shot* technologies.

In order to disentangle the role played by the above dimensions of biodiversity, we carry the analysis following a progressive sophistication approach. Section 2 starts with a simple resource allocation problem, cast as a two input-two output model. A southern country allocates optimally land and capital to two productive activities, agriculture and tourism. The tourism production function is based on unspoilt land (forests, wetlands, etc.) which carries biodiversity, whereas agricultural production requires land to be converted into pasture and arable land with neither local nor global biodiversity value. If social utility is defined as a strictly concave separable function of revenue and biodiversity, then we show that an increase in the country's investment capacity can either induce more land conservation -and therefore more biodiversity- or more land conversion -and therefore less biodiversity- , depending on the relative marginal productivity of land and capital in the two competing activities. Therefore this model provides a renewed interpretation of the Kuznets' environmental curve, based on production economics instead of consumer choice economics.

In Section 3, the same result is obtained when the local benefits of land conservation are a local public good shared between two identical neighbouring countries, which use it as an input into their tourism production function. The neutrality of positive income shocks for the two countries is only observed when there are no substitution or complementarities effects between land and capital in the two activities.

Section 4 then assesses the impact of income transfers from an ecosystem-poor country (the North) to two ecosystem-rich countries (the South) sharing a common ecosystem. Warr's neutrality property generally collapses. When income redistribution induces an increase of biodiversity, we demonstrate that there are cases for which it is a Pareto-improving policy. Less intuitively, it is shown that Pareto improving transfers are still possible even when they induce the south to settle for a lower level of biodiversity. In a context favouring conditional transfers, that is payments made in proportion to conservation efforts (such as conservation projects financed by the Global Environmental Fund), this result indicates that lump-sum transfers between countries are policy instruments which are worth investigating since they can provide the incentives to go in the right direction with no control and monitoring costs.

2 Biodiversity and agriculture-tourism trade-off in a simple model

Consider a southern country endowed with a naturally biodiversity-rich land (natural pastures, wetlands, forests) providing a number of ecological services such as flood protection or climate regulation and which are essential assets for developing green tourism activities. This land area I is potentially convertible (ploughing, deforestation, drainage) into arable land for agricultural production. Let s_a denote the surface converted into arable land and let s_n denote the unconverted natural land (also called *natural capital*). By definition, $s_n + s_a = I$. The country is also endowed with an exogenous national wealth w; a share $x \in [0,1]$ of w can be used as monetary expenditures in tourism, R_T, the remaining part $(1-x)$ being then used as monetary expenditures in agriculture, R_A. Of course $R_T + R_A = wx + (1-x)w = w$.

The production technology in the touristic sector, $\bar{T}(s_n, R_T)$, requires two inputs, unspoilt land and money, whereas the agricultural technology, $\bar{A}(s_a, R_A)$, combines farmland, which does not carry any valuable biodiversity, with money. Both functions are increasing, twice differentiable and strictly concave with respect to each of their arguments.

Without loss of generality, units of outputs, in each sector, are chosen so that unit prices are both equal to one. So the total revenue from production is simply $\bar{T}(s_n, R_T) + \bar{A}(s_a, R_A)$. To obtain the net revenue, one must substract costs. With linear costs, the profits in the two sectors are $T(s_n, R_T) = \bar{T}(s_n, R_T) - c_n s_n - r_T R_T$ and $A(s_a, R_A) = \bar{A}(s_a, R_A) - c_a s_a - r_A R_A$, where c_n and c_a are the unit costs of natural land and arable land; respectively r_T and r_A are the unit opportunity costs of monetary expenditures in tourism and in agriculture. Then the net total revenue is $y = T(s_n, R_T) + A(s_a, R_A)$. We shall assume that the costs of inputs are sufficiently low, so that $T(.)$ and $A(.)$ are increasing functions in each of their arguments. Four last technical assumptions regarding profits are made to rule out corner decisions throughout the whole analysis:

A1 $\frac{\partial}{\partial s_n} T(0, R_T) - \frac{\partial}{\partial s_a} A(I, R_A) > 0, \ \forall R_T, \ R_A \in [0, w]$,

A2 $\frac{\partial}{\partial s_n} T(I, R_T) - \frac{\partial}{\partial s_a} A(0, R_A) < 0, \ \forall R_T, \ R_A \in [0, w]$,

A3 $\frac{\partial}{\partial R_T} T(s_n, 0) - \frac{\partial}{\partial R_A} A(s_a, w) > 0, \ \forall s_n, \ s_a \in [0, I]$,

A4 $\frac{\partial}{\partial R_T} T(s_n, w) - \frac{\partial}{\partial R_A} A(s_a, 0) > 0, \ \forall s_n, \ s_a \in [0, I]$.

Finally, the country's utility is $U(y, s_n)$, a differentiable function, strictly increasing in each argument and globally concave. Clearly natural land is both a consumption good - associated with the biodiversity value of land -, and an input - in the tourism production function.

The country chooses s_n and x in order to maximize total utility:

$$\max_{s_n \in [0,I], x \in [0,1]} U(y, s_n)$$

The first-order conditions for interior solutions are written:

$$\frac{\partial U}{\partial s_n} = U_1(T_1 - A_1) + U_2 = 0 \Longleftrightarrow T_1 - A_1 = -\frac{U_2}{U_1} = -TMS\ , \qquad (1)$$

$$\frac{\partial U}{\partial x} = wU_1(T_2 - A_2) = 0 \Longleftrightarrow T_2 = A_2\ , \qquad (2)$$

where TMS is the *marginal rate of substitution between net revenue and natural capital*, and where $U_1 = \frac{\partial U}{\partial y}$ and $U_2 = \frac{\partial U}{\partial s_n}$ are the partial derivatives of the utility function with respect to y and s_n respectively, $T_1 = \frac{\partial T}{\partial s_n}$, $T_2 = \frac{\partial T}{\partial R_T}$, $A_1 = \frac{\partial A}{\partial s_a}$, $A_2 = \frac{\partial A}{\partial R_A}$ are partial derivatives of the sectorial profit functions with respect to s_n, R_T, s_a, and R_A.

This is a model of optimal allocation of factors between two activities. The vector of optimal decisions $d^* = (s_n^*, x^*)$ is reached when the difference in land marginal revenue is equal to the marginal rate of substitution (1) and when marginal revenue of monetary expenditures are equal in the two production sectors (2).

2.1 Monetary transfers and resources allocation

Let the utility function be $U(y, s_n) = y + \varepsilon N(s_n)$, with $\varepsilon > 0$ a strictly positive parameter and $N(.)$ a continuous function, increasing and concave with respect to s_n that converts an area of natural land into a biodiversity index. For instance, if the biodiversity index is the $\alpha-$biodiversity, that is the number of species in the area under conservation, then the functional form is usually written: $N(s_n) = bs_n^z$, with $b > 0$ and $z \in [0, 1]$. Note that, with this choice of utility function, $TMS = \frac{U_2}{U_1} = \varepsilon N'$.

A monetary transfer to the country (in the form of lump-sum subsidy from an international organization, or bilateral aid) increases its wealth w. In the appendix, we show that it will induce a marginal change in the optimal allocation of land which is:

$$\left.\frac{ds_n}{dw}\right|_{d=d^*} = \frac{A_{12}T_{22} - A_{22}T_{12}}{[T_{11} + A_{11} + \varepsilon N''][T_{22} + A_{22}] - [T_{12} + A_{12}]^2} \qquad (3)$$

where $A_{11} = \frac{\partial A_1}{\partial s_a} > 0$, $A_{22} = \frac{\partial A_2}{\partial R_a} > 0$, $T_{11} = \frac{\partial T_1}{\partial s_n} > 0$, $T_{22} = \frac{\partial T_2}{\partial R_T} > 0$, $A_{12} = \frac{\partial A_1}{\partial R_a}$, $T_{12} = \frac{\partial T_1}{\partial R_T}$ are the second order partial derivatives of the net revenue function.

From expression (3), one can readily deduce the conditions under which a monetary transfer has no effect (marginally) on the natural capital. At the most general level, neutrality obtains when the numerator is zero, that is:

$$A_{12}T_{22} - A_{22}T_{12} = 0 \ .$$

A priori, this general condition encompasses five subcases: $i)$ $A_{12} = A_{22} = 0$, $ii)$ $T_{22} = T_{12} = 0$, $iii)$ $T_{22} = A_{22} = 0$, $iv)$ $A_{12} = T_{12} = 0$, $v)$ $A_{12}T_{22} = A_{22}T_{12}$ with $A_{12}, T_{22}, A_{22}, T_{12} \neq 0$. Possibilities $i) - iii)$ are ruled out by the assumptions of strict concavity made so far on the production technologies. Let us discuss the two last ones. Possibility $iv)$ depends only on the technologies, whereas possibility $v)$ is more subtle as it may also depend on the way resources are re-allocated after a change in w.

Proposition 1 *If there are no complementary or substitution cross effects between land and monetary expenditures, i.e.* $A_{12} = T_{12} = 0$, *then a financial transfer to the country has no impact on natural capital,* $\frac{ds_n}{dw}\Big|_{d=d^*} = 0$.

This property does not mean that the second decision variable x is unaffected. Actually a change in the initial wealth induces a change in the allocation of monetary expenditures (a change in x), which is:

$$\left.\frac{dx}{dw}\right|_{d=d^*} = -\frac{xT_{22} + A_{22}(x-1)}{w(T_{22} + A_{22})} \ . \tag{4}$$

But, by assumption this has no effect whatsoever on the marginal revenues T_1 and A_1, therefore no effect on the optimal s_n as can be deduced from the first order condition (1).

Proposition 2 *if* $A_{12}T_{22} = A_{22}T_{12}$ *with* $A_{12}, T_{22}, A_{22}, T_{12} \neq 0$*, then a financial transfer to the country has no impact on natural capital,* $\frac{ds_n}{dw}\Big|_{d=d^*} = 0$

It should be realized that this second case exists even when $A_{12}, T_{22}, A_{22}, T_{12} \neq 0$ are not constants. When those second derivatives vary with the level of natural capital and the level of monetary investments, Proposition 2 singles out the case where the monetary transfer induces a reallocation of monetary expenditures such that the first order conditions $T_1 - A_1 = -\frac{U_2}{U_1}$ are verified at the unchanged optimal level of natural capital s_n (see figure 1 below):

Incidentally, this situation supposes that the cross partial derivatives have the same sign.

Those particular cases excepted, natural capital increases or decreases with income. With a slight abuse of language we shall borrow two notions from the consumer theory and say that natural capital is a *normal good* when $\frac{ds_n}{dw}\Big|_{d=d^*} > 0$, and an *inferior good* when $\frac{ds_n}{dw}\Big|_{d=d^*} < 0$.[2]

[2] The choice of term "normal good" or "inferior good" is partially inexact since s_n is not only a consumption good (in the second part of the utility function) but also an input in the net revenue functions.

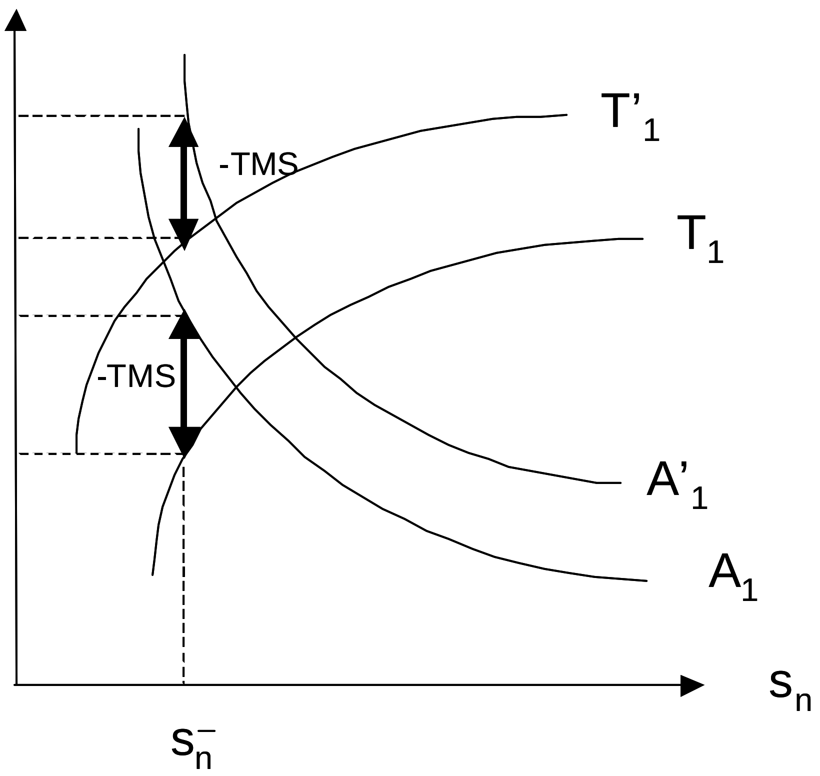

Figure 1:

It is worth interpreting those results in the light of the Kuznets' environmental curve hypothesis (KEC). The KEC is an empirical statistical result showing an inverted U-shaped relationship between environmental degradation and per capita income. It tends therefore to indicate that beyond a turning point, economic growth can lead to environmental improvement. The usual intuitive explanation for this phenomenon is that the pure scale effect (production growth leads to an increase in pollution and resource exploitation) is compensated by improvements in green technologies driven by a higher demand for environmental quality (Stern, 2004). However, the KEC is a controversial result: an increasing number of econometric studies show that there are no regularities in the revenue-environment relationship, especially when one looks at resource depletion rather than pollution concentration (see Koop and Tole, 1999 for a study on deforestation). Surprisingly, there is relatively little formal modelling exploring the micro-economic foundations of the KEC, although this could be very useful to explain the different curves observed empirically. Bulte and van Soest (2001) propose a household model of optimal allocation of work and investment when natural capital is an input in production, and show that under the imperfect market hypothesis the U-shaped relation between natural capital stock and income can be generated.

Our optimal production model provides the theoretical basis for an explanation of the KEC rooted in production economics. We have shown above how natural capital can decrease or increase with wealth depending on the relative concavity parameters of our production functions for tourism and agriculture $(A_{11}, A_{22}, A_{12}, T_{12})$. The intuition is the following: when agricultural production increases, therefore driving up income, the relative marginal productivity of land and expenses in this sector decline, making it more profitable to invest in tourism and protect natural capital. We intend, in a subsequent version of this paper, to introduce examples of production functions which could illustrate the KEC and more generally reproduce the results found in Koop and Tole (1999) in the case of deforestation .

2.2 Monetary transfers and total utility

Changes in utility associated with monetary transfers are written:

$$\begin{aligned}
\left.\frac{dU}{dw}\right|_{d=d^*} &= U_1 \left.\frac{dy}{dw}\right|_{d=d^*} + U_2 \left.\frac{ds_n}{dw}\right|_{d=d^*} , \\
&= U_1 \left[(T_1 - A_1) \left.\frac{ds_n}{dw}\right|_{d=d^*} + (wT_2 - wA_2) \left.\frac{dx}{dw}\right|_{d=d^*} + xT_2 + (1-x)A_2 \right] \\
&\quad + U_2 \left.\frac{ds_n}{dw}\right|_{d=d^*} .
\end{aligned}$$

Using the first order conditions (1) and (2), this expression simplifies to:

$$\left.\frac{dU}{dw}\right|_{d=d^*} = A_2 \geq 0.$$

As the intuition suggests, total utility increases when wealth increases.

3 The local public good dimension of biodiversity

It is often the case that natural capital has in fact cross-border spillovers. For example, a large forest area, or wetlands, will presumably benefit neighbouring countries by preserving wildlife habitats and landscapes and therefore will increase the attractiveness of the whole region for tourism. Conversely, if a country chooses to reduce the quality and size of its preserved land, it will probable harm as well the whole region by reducing ecological services and amenities. Therefore, in many cases, s_n is a regional public good: there is neither exclusion nor rivalry in consumption, so countries in the same region benefit from it. Examples abound: lake Victoria in East Africa, the Amazon forest in South America, the mangroves in South East Asia.

Let us assume that the southern country described in the previous section is split into two identical sovereign countries sharing a common border ($i = 1, 2$). Each country has an initial endowment in natural capital $I^i = I/2$ and an initial level of wealth $w^i = w/2$.

Production functions and utility functions are unchanged. Each country i has to choose the optimal allocation of land (s_{ni}) and monetary expenditures (x_i) between the two activities, tourism and agriculture. There are two differences with the previous basic model. Firstly, $s_n = \sum s_{ni}$ is a regional public good. Each country benefits from it both as an input in the tourism production function and as a consumption good. Secondly and consequently, there are now strategic interactions.

3.1 Monetary transfers and resource allocation

Non cooperative decisions $d_i = (s_{ni}, x_i)$, $i = 1, 2$ are conceptualized as a Nash equilibrium. Each country selects its contribution s_{ni} to the public good/*input* and the allocation x_i of monetary expenditures between tourism and agriculture in order to maximize total utility, taking as given the decision variables of the other country. Formally, country i's problem reads as:

$$\max_{s_{ni}\in[0,I/2], x_i\in[0,1]} U^i(y^i, s_{ni} + s_{nj})$$

where

- $y^i = T(s_{ni} + s_{nj}, R_T^i) + A(\frac{I}{2} - s_{ni}, R_A^i)$ is country i 's total net revenue,

- $R_T^i = \frac{1}{2}wx_i$ and $R_A^i = \frac{1}{2}w(1-x_i)$ are the monetary expenditures dedicated respectively to tourism and agriculture,
- and s_{nj} and x_j are considered as exogenously given.

The first-order conditions for $i = 1, 2$ are:

$$\begin{aligned}
\frac{\partial U^i}{\partial s_{ni}} &= U_1^i(T_1 - A_1) + U_2^i = 0 \Longleftrightarrow T_1 - A_1 = -\frac{U_2^i}{U_1^i} = -TMS^i, \\
\frac{\partial U^i}{\partial xi} &= \frac{1}{2}wU_1^i(T_2 - A_2) = 0 \Longleftrightarrow T_2 = A_2.
\end{aligned}$$

Definition 3 *A interior symmetric Nash equilibrium (ISNE) for the two-country economy is a profile of decisions* $\overline{d} = (\overline{s}_{n1}, \overline{s}_{n2}, \overline{x}_1, \overline{x}_2) = \left(\frac{1}{2}\overline{s}_n, \frac{1}{2}\overline{s}_n, \overline{x}, \overline{x}\right)$ *, such that countries simultaneously solve their decision problems given the decisions of the other country.*

Note that, at such a symmetric outcome, $TMS^1 = TMS^2 = TMS$.

For $U^i(y_i, s_n) = y_i + \varepsilon N(s_n)$, we can calculate the impact of a change in wealth on x and on s_n, evaluated at an ISNE:

$$\left.\frac{dx}{dw}\right|_{d=\overline{d}} = -\frac{2T_{21} + A_{21}}{w(T_{22} + A_{22})} \left.\frac{ds_n}{dw}\right|_{d=\overline{d}} - \frac{xT_{22} - (1-x)A_{22}}{w(T_{22} + A_{22})} \tag{5}$$

$$\left.\frac{ds_n}{dw}\right|_{d=\overline{d}} = \frac{A_{12}T_{22} - A_{22}T_{12}}{(2T_{11} + A_{11} + 2\varepsilon N'')(T_{22} + A_{22}) - (T_{12} + A_{12})(2T_{21} + A_{21})} \tag{6}$$

Results are comparable to those found in the first section.

3.2 Monetary transfers and social welfare

Let us consider an utilitarian social welfare function, that is to say:

$$W = U^1(y_1, s_n) + U^2(y_2, s_n)$$

At an ISNE we have:

$$\left.\frac{dW}{dw}\right|_{d=\overline{d}} = 2\left.\frac{dU^i}{dw}\right|_{d=\overline{d}} = 2\left[U_1^i \left.\frac{dy}{dw}\right|_{d=\overline{d}} + U_2^i \left.\frac{ds_n}{dw}\right|_{d=\overline{d}}\right] = 2\left[\left.\frac{dy}{dw}\right|_{d=\overline{d}} + \varepsilon N' \left.\frac{ds_n}{dw}\right|_{d=\overline{d}}\right], \tag{7}$$

where:

$$\left.\frac{dy}{dw}\right|_{d=\bar{d}} = T_1 \left.\frac{ds_n}{dw}\right|_{d=\bar{d}} + \frac{1}{2}xT_2 - \frac{1}{2}A_1 \left.\frac{ds_n}{dw}\right|_{d=\bar{d}} + \frac{1}{2}(1-x)A_2 \ , \qquad (8)$$

$$= \left(T_1 - \frac{1}{2}A_1\right) \left.\frac{ds_n}{dw}\right|_{d=\bar{d}} + \frac{1}{2}A_2 \ . \qquad (9)$$

Therefore

$$2\left.\frac{dy}{dw}\right|_{d=\bar{d}} = (T_1 + T_1 - A_1) \left.\frac{ds_n}{dw}\right|_{d=\bar{d}} + A_2 \ ,$$

$$= (T_1 - \varepsilon N') \left.\frac{ds_n}{dw}\right|_{d=\bar{d}} + A_2 \ . \qquad (10)$$

Plugging back expression (10) into expression (7), one obtains:

$$\left.\frac{dW}{dw}\right|_{d=\bar{d}} = T_1 \left.\frac{ds_n}{dw}\right|_{d=\bar{d}} + A_2 \ . \qquad (11)$$

The marginal variation of social welfare depends on the behaviour of $\frac{ds_n}{dw}\big|_{d=\bar{d}}$. Remember that in an economy with a single country, the utility increases after a positive shock to income. By contrast, in a two-country world, expression (11) shows that the variation of each country's utility is ambiguous.

Proposition 4 *If* $\frac{ds_n}{dw}\big|_{d=\bar{d}} = 0$, *i.e. a change in total income produces no change on the public good production, then* $\frac{dW}{dw}\big|_{d=\bar{d}} = A_2 > 0$.

In this case, when one of the two conditions for $\frac{ds_n}{dw} = 0$ is met (cf. sections 2.1 and 3.1), then an exogenous increase of income always ends up in an improvement of social welfare, although it has no effect on the public good provision. This is due, as in Section 3.1, to an optimal reallocation of investments between the two economic activities. In all other cases, when $\frac{ds_n}{dw} \neq 0$, the two following clear-cut properties hold:

Proposition 5 *If* s_n *is a normal good, then* $\frac{dW}{dw}\big|_{d=\bar{d}} > 0$.

Proposition 5 singles out a sufficient, easy-to-interpret and empirically testable condition (normality), for a positive social welfare impact. But the necessary and sufficient condition is:

Proposition 6 $\frac{dW}{dw}\big|_{d=\bar{d}} \geq 0$ *iff* $\frac{ds_n}{dw} \geq -\frac{A_2}{T_1}$.

Therefore there can be Pareto improving transfers even if s_n is akin to an inferior good, provided that $\frac{ds_n}{dw} < 0$ is not too small. To put it differently, the variation of social welfare depends on the sign of $\frac{ds_n}{dw}$; and it depends on its scale (when $\frac{ds_n}{dw} < 0$).

Finally, when $\frac{ds_n}{dw} < -\frac{A_2}{T_1} < 0$ then $\frac{dW}{dw} < 0$ and lump sum transfers have a negative impact both on the conservation of natural capital and on welfare.

4 Adding the global public good dimension of biodiversity

4.1 A simple north-south model

In the example of a wetland spreading over two neighbouring countries, the lake is a local public good; it delivers water storage services, purification services, and so on... Those services benefit without rivalry to the citizens of both countries. The lake is also a public input providing amenities to both countries and therefore entering as an argument in their tourism production functions. In addition, the preservation of the lake ecosystem contributes to improve the quality of global biodiversity and generates world-wide benefits. From a general perspective, those global benefits should be taken into account. Following this idea, we add a northern distant country in the conceptual framework. This third country does not share the regional benefits of the lake because of, say, geographical distance but it shares the benefits of the gene pool conservation.

Formally, a three-country economy, $i = 1, 2, 3$ allows one to add the global public good dimension to the natural capital. This global public good is denoted: $G = G(s_{n1}, s_{n2}, g_3) = N(s_n) + g(g_3)$ where g_3 is the financial contribution of the third country. The functions N and g are both continuous, increasing and concave. Note the heterogeneity of the inputs: in the model, the natural area is localized in the first two countries; the third countries is not endowed with the natural potential for conservation, but it can offer monetary contributions to R&D efforts that convert genetic diversity into pharmaceutical innovations, which in turn are beneficial for public health.

As in the previous section, the focus shall be on the effect of income transfers on the Nash equilibrium, therefore on the equilibrium trade-off between the two activities of tourism and agriculture, with one difference though: transfers are not considered as exogenous income shocks anymore; they shall be organized from the northern country towards southern countries. In other words, we finally explore the question of the impact of income redistribution on the level of biodiversity and welfare.

As for country 3, its utility reads as $U^3(c_3, G) = v(c_3) + \sigma G$, where $v(c_3)$ is a concave and increasing function of private good consumption $c_3 = w_3 - g_3$, and $\sigma > 0$ represents a preference parameter for the global public good G. This country has only one decision variable: the level of monetary contribution g_3 to the production of biodiversity. To avoid corner decisions we assume:

A5 $-v'(w_3) + \sigma g'(0) > 0$,

A6 $-v'(0) + \sigma g'(w_3) < 0$.

The utility functions of country $i = 1, 2$ is now $U^i(y_i, G) = y_i + \varepsilon G$. Southern countries have the same preference for the global public good.

Definition 7 *A interior symmetric Nash equilibrium (ISNE) for the three-country economy is a profile of decisions* $\widehat{d} = (\widehat{s}_{n1}, \widehat{s}_{n2}, \widehat{x}_1, \widehat{x}_2, \widehat{g}_3)$, *such that* *countries simultaneously solve their decision problems given the decisions of the other countries.*

More precisely, on a non cooperative basis each country takes as given rival decisions and uses its own decisions to maximize its utility:

- for $i = 1, 2$:
$$\max_{s_{ni} \in [0, I/2], x_i \in [0,1]} U^i(y_i, G(s_{n1}, s_{n2}, g_3))$$
subject to $y_i = T(s_{ni}, R_T^i) + A(I/2 - s_{ni}, R_A^i)$. At an interior Nash equilibrium for $i = 1, 2$, we have:

$$T_1 - A_1 = -\frac{U_2}{U_1} = -TMS = -\varepsilon N'(s_n) \ , \tag{12}$$
$$T_2 = A_2 \ . \tag{13}$$

- and for $i = 3$:
$$\max_{g_3 \in [0, w_3]} U^3(w_3 - g_3, G(s_{n1}, s_{n2}, g_3))$$
The first order condition for an interior decision is:

$$-U_1^3 + U_2^3 g' = 0 \tag{14}$$

It should be noted that this system of five equations is decomposable into two independent blocks: the first one is a system of four equations for four unknown $(s_{n1}, s_{n2}, x_1, x_2)$ and the second block is made of a single equation for g_3. Differentiating the last equation with respect to g_3 and w_3, one can deduce the marginal impact of income on the third country's contribution:

$$U_{11}^3 dg_3 - U_{11}^3 dw_3 - U_{12}^3 g' dg_3 - U_{21}^3 g' dg_3 + U_{21}^3 g' dw_3 + U_{22}^3 (g')^2 dg_3 + U_2^3 g'' dg_3 = 0 \ ,$$
$$\Leftrightarrow \quad (U_{11}^3 - U_{12}^3 G' - U_{21}^3 G' + U_{22}^3 G'') dg_3 + (-U_{11}^3 + U_{21}^3 G') dw_3 = 0$$

According to our assumption of additive separability of utility functions, $U_{12}^3 = U_{21}^3 = 0$, and we get:

$$(U_{11}^3 + U_{22}^3 g'') dg_3 - U_{11}^3 dw_3 = 0$$

and

$$\left.\frac{dg_3}{dw_3}\right|_{d=\widehat{d}} = \frac{U_{11}^3}{(U_{11}^3 + U_{22}^3 g'')} > 0 \tag{15}$$

Expression (15) confirms, under particular assumptions, the intuition that a contribution to a public good increases when income increases. Besides, one can observe that $0 < \frac{dg_3}{dw_3} < 1$.

4.2 Welfare effect of a lump sum transfer between countries

What is the welfare effect of a lump sum income redistribution from the North to the South, given the complex public good nature of biodiversity? Let us study a transfer from country 3 that is shared equally by country 1 and country 2.

The utilitarian social welfare function is given by:

$$W = U^1(y_1, G) + U^2(y_2, G) + U^3(c_3, G)$$

Following a lump sum transfer $-dw_3 = dw_1 + dw_2 = 2dw$, one has:

$$dW = U_1^1 dy_1 + U_2^1 dG + U_1^2 dy_2 + U_1^2 dG + U_1^3 dc_3 + U_1^3 dG \tag{16}$$

where

1. $dy_1 = dy_2 = dy = [(T_1 - \frac{1}{2}A_1)\frac{ds_n}{dw} + \frac{1}{2}A_2]dw$ (according to expression (8) of the previous section),
2. $dG = N'\frac{\partial s_n}{\partial dw_1}dw_1 + N'\frac{\partial s_n}{\partial dw_2}dw_2 + g'(g_3)\frac{\partial g_3}{\partial dw_3}dw_3$,
3. $dc_3 = dw_3 - \frac{\partial g_3}{\partial dw_3}dw_3$.

Plugging back the previous expressions into expression (16), one obtains:

$$\begin{aligned} dW &= U_1^1 dy_1 + U_2^1 dG + U_1^2 dy_2 + U_2^2 dG + U_1^3 dc_3 + U_2^3 dG \ , \\ &= (U_1^1 + U_1^2)dy + (U_2^1 + U_2^2 + U_2^3)dG + U_1^3 dc_3 \ , \end{aligned}$$

or

$$\begin{aligned} dW &= 2\left[(T_1 - \frac{1}{2}A_1)\frac{ds_n}{dw} + \frac{1}{2}A_2\right]dw \\ &\quad +(2\varepsilon + \sigma)\left[N'\frac{\partial s_n}{\partial dw_1}dw_1 + N'\frac{\partial s_n}{\partial dw_2}dw_2 + g'(g_3)\frac{\partial g_3}{\partial dw_3}dw_3\right] \\ &\quad +v'(c_3)\left(dw_3 - \frac{\partial g_3}{\partial dw_3}dw_3\right) \ . \end{aligned}$$

Bearing in mind that $dw_3 = -2dw$, this expression simplifies to:

$$\begin{aligned} \frac{dW}{dw} &= 2(T_1 - \frac{1}{2}A_1)\frac{ds_n}{dw} + A_2 \\ &\quad +(2\varepsilon + \sigma)\left[N'(\frac{\partial s_n}{\partial w} + \frac{\partial s_n}{\partial w}) - 2g'(g_3)\frac{\partial g_3}{\partial w_3}\right] \\ &\quad -2v'(c_3)\left(1 - \frac{\partial g_3}{\partial w_3}\right) \ . \end{aligned}$$

So, at an ISNE:

$$\left.\frac{dW}{dw}\right|_{d=\widehat{d}} = 2(T_1-\frac{1}{2}A_1)\frac{ds_n}{dw}+A_2+2(2\varepsilon+\sigma)\left[N'\frac{ds_n}{dw}-g'(g_3)\frac{dg_3}{dw_3}\right]-2v'(c_3)\left(1-\frac{\partial g_3}{\partial w_3}\right).$$

From the first order condition (14), where $-v'(c_3)+\sigma g'(g_3)=0$, this can be rewritten:

$$\left.\frac{dW}{dw}\right|_{d=\widehat{d}} = \left[T_1+(3\varepsilon+2\sigma)\,N'\right]\frac{ds_n}{dw}+A_2-4\varepsilon g'(g_3)\frac{dg_3}{dw_3}-2v'(c_3)\ . \qquad (17)$$

Equipped with this expression, it is easy to deduce:

Proposition 8 *A lump sum transfer is welfare improving,* $\left.\frac{dW}{dw}\right|_{d=\widehat{d}}>0$*, iff* $A_2>4\varepsilon g'(g_3)\frac{dg_3}{dw_3}+2v'(c_3)-\left[T_1+(3\varepsilon+2\sigma)\,N'\right]\frac{ds_n}{dw}$.

This proposition shows in particular that, even when the public good is an inferior good, a lump sum transfer from a country that does not produce it towards countries that do produce it, or do use it in their production activities, is Pareto improving if the profitability of investments in the latter compensates for the overall negative effects of the transfer on the production of the public good and on the private consumption of the donor country. Of course when the public good is a normal good, the conditions required to guarantee a positive welfare effect are obviously less stringent. For instance it is sufficient that $A_2>4\varepsilon g'(g_3)\frac{dg_3}{dw_3}+2v'(c_3)$.

Otherwise, $\frac{dW}{dw}<0$, and it would be justified, from the point of view of efficiency, to organize transfers from the South to the North! The logic that explains this possibility is not difficult to grasp, but this is a rather provocative and hard to admit conclusion. As a mitigation, one should bear in mind that transfer policies are primarily designed to pursue equity goals rather than efficiency goals.

The policy implication of this section is simple: an income transfer must be preceded by an empirical study which is not limited to an estimation of the question of whether s_n is an inferior good. Those results suggest that a precise knowledge of production technologies is valuable if one wishes to expand the protection of biodiversity and to increase welfare by means of income redistribution. In particular, this knowledge must be sufficiently precise about the cross effects between land capital and investments (T_{12}, A_{12}), about the extent of decreasing returns (T_{11}, T_{22}, A_{11}, A_{22}) and about the marginal products (T_1, T_2, A_1, A_2). In addition, we have shown that the additivity of the production technology for the public good is not sufficient for the robustness of Warr's neutrality theorem. Indeed, the welfare variation is generally not null after an income redistribution between the three countries, even if the redistribution does not change the set of contributors.

5 Conclusion

How do those results compare with those established by Warr and Sandler? Those authors show that income transfers between contributors are neutral on the provision of private public goods produced via an additive technology. When dealing with biodiversity, a multidimensional public good, we have shown that the assumption of additive technology does not guaranty the neutrality property. Indeed, the non neutrality is the rule while neutrality is the exception. Here the input dimension of the public good plays a key role. Furthermore, the nature of the public good biodiversity, i.e. normal good or inferior good, is helpful in assessing the welfare effect of marginal income redistributions. Normality makes a stronger case in favor of lump sum transfers as a tool for the protection of biodiversity. However, it should be reminded that Pareto improvements without modification, or even with a reduction of the level of biodiversity are possible. When both the local dimension and the global dimension of the public good are considered, the effects of income redistribution are complex and their assessment require a precise knowledge of the production technologies.

Appendix

Variation of the conservation effort in an economy with a single country - Section 2

Starting from the optimal decision vector $d^* = (s_n^*, x^*)$ and differentiating the first order conditions with respect to w, s_n and x, it follows:

$$\left\{ \begin{array}{c} [xT_{12} - (1-x)A_{12}]\,dw + [T_{11} + A_{11} + \varepsilon N'']ds_n + [wT_{12} + wA_{12}]dx = 0 \ , \\ [xT_{22} - (1-x)A_{22}]dw + [T_{21} + A_{21}]ds_n + [wT_{22} + wA_{22}]dx = 0 \ . \end{array} \right.$$

After dividing each of those expressions by dw, one obtains:

$$\left\{ \begin{array}{c} [T_{11} + A_{11} + \varepsilon N'']\frac{ds_n}{dw} + [T_{12} + A_{12}]w\frac{dx}{dw} + [xT_{12} - (1-x)A_{12}] = 0 \\ [T_{21} + A_{21}]\frac{ds_n}{dw} + [wT_{22} + wA_{22}]\frac{dx}{dw} + [xT_{22} - (1-x)A_{22}] = 0 \end{array} \right.$$

From the second equation:

$$\frac{dx}{dw} = -\frac{[T_{21} + A_{21}]}{w[T_{22} + A_{22}]}\frac{ds_n}{dw} - \frac{[xT_{22} - (1-x)A_{22}]}{w[T_{22} + A_{22}]} \tag{18}$$

Plugging expression (18) into the first equation of the system, we have:

$$[T_{11} + A_{11} + \varepsilon N'']\frac{ds_n}{dw} - \frac{[T_{12} + A_{12}][T_{21} + A_{21}]}{[T_{22} + A_{22}]}\frac{ds_n}{dw}$$
$$-\frac{[T_{12} + A_{12}][xT_{22} - (1-x)A_{22}]}{[T_{22} + A_{22}]} + [xT_{12} - (1-x)A_{12}] = 0$$

$$\frac{[T_{11}+A_{11}+\varepsilon N''][T_{22}+A_{22}]-[T_{12}+A_{12}][T_{21}+A_{21}]}{[T_{22}+A_{22}]}\frac{ds_n}{dw}$$
$$-\frac{[T_{12}+A_{12}][xT_{22}-(1-x)A_{22}]-[T_{22}+A_{22}][xT_{12}-(1-x)A_{12}]}{[T_{22}+A_{22}]}=0$$

and therefore:

$$\begin{aligned}\left.\frac{ds_n}{dw}\right|_{d=d^*} &= \frac{[T_{12}+A_{12}][xT_{22}-(1-x)A_{22}]-[T_{22}+A_{22}][xT_{12}-(1-x)A_{12}]}{[T_{11}+A_{11}+\varepsilon N''][T_{22}+A_{22}]-[T_{12}+A_{12}][T_{21}+A_{21}]} \\ &= \frac{A_{12}T_{22}-A_{22}T_{12}}{[T_{11}+A_{11}+\varepsilon N''][T_{22}+A_{22}]-[T_{12}+A_{12}]^2}\end{aligned} \quad (19)$$

The simplification of expression (19) is reported in Section 2.1 (expression (3)).

References

[1] Bergstrom T.C., Blume L.E. and Varian H.R., 1986,"On the private provision of public goods", *Journal of Public Economics*, 29, 25-49.

[2] Bulte E. and van Soest D., 2001, “Environmental degradation in developing countries: households and the (reverse) environmental Kuznets curve”, *Journal of Development Economics*, 65, 225-235.

[3] Cornes R. and Sandler T., 1984, "Easy riders, joint production and public goods", *Economic Journal*, 94(3), 580-98.

[4] Cornes R. and Sandler T., 1985, "The simple analytics of pure public good provision", *Economica*, 52, 103-116.

[5] Hirshleifer J., 1983, "From weakest-link to Best-shot: the voluntary provision of public goods", *Public Choice,* 41(3), 371-86.

[6] Itaya J.-I., de Meza D. and Myles G., 1997, "In praise of inequality: public good provision and income distribution", *Economics Letters*, 57, 289-296.

[7] Koop G. and Tole L., 1999, “Is there an environmental Kuznets curve for deforestation?”, *Journal of Development economics,* 58, 231-244.

[8] Stern D., 2004, “The rise and fall of the environmental Kuznets curve”, *World Development,* 32n(8), 1419-1439.

[9] Warr P., 1983, "The private provision of public goods is independent of the distribution of income", *Economic Letters*, 13, 207-211.