International Biodiversity Management with Technological Change

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Abstract

I consider an economy where the conservation of land yields utility through biodiversity, firms improve their efficiency by in-house R&D and a number of countries establish a self-interested international agency for biodiversity management. I compare the regulation of land use with direct subsidies for conserved land and obtain following results. Regulation promotes biodiversity and economic growth. Because revenue-rasing taxes hamper growth, the replacement of regulation by subsidies decreases biodiversity, growth and welfare. Applied to NATURA 2000 in the EU, this suggests that regulation without any budget is the appropriate degree of authority for the Commission.

Keywords: Biodiversity, conservation subsidies, in-house R&D, land-use regulation, lobbying, technological change

Journal of Economic Literature: 041, H23, F15, Q24

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1 Introduction

This document considers optimal institutional design of biodiversity management under lobbying, with a special focus on the following problems. Should biodiversity management be run by an international agency or by individual countries independently? How much authority should this agency get? Are regulatory powers sufficient, or should the international agency have a budget to finance conservation subsidies, for instance?

The framework for this study is based on the following experience. The "international agency" called the European Commission (EC) manages biodiversity and two directives regulate nature conservation in the the European Union (EU) (cf. Ostermann 1998):

- Birds Directive 79/409/EEC on the conservation of wild birds;
- Habitats Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.

The Habitats Directive calls for the establishment of a network of designated sites, called Natura 2000, which will consist of sites designated under the Habitats Directive (Special Areas of Conservation, SACS) and the Birds Directive (Special Protection Areas, SPAS). These directives contain annexes with habitats and species listed as being of Community interest, and whose conservation requires the designation of sites by the Member States. A Member State is obliged to guarantee a "Favorable Conservation Status", which is defined in the Habitats Directive, to a Natura 2000 site with the obligations of monitoring and reporting.

Non-governmental organizations (NGOs) play a crucial role in the highly complex political structure of the EU. Weber and Christophersen (2002) describe the political influence of the forest-owner associations (CEPF and BNFF) and the environmental NGOs (WWF and Fern) on the process of implementing the EU habitats directive (HD). They highlight the relationship between the involvement of interest groups in the political process and the acceptance of legislation among their members. In this paper, I examine the political equilibrium in which the interest groups representing the member countries lobby the Commission over biodiversity management.

There are three reasons why EU policy relies heavily on regulation rather than on other mechanisms to achieve its objectives (Ledoux et al. 2000).

- Until 1987, EU environmental policy lacked a proper legal basis in the founding Treaty of Rome. Consequently, all environmental policies had to rely on the "implied powers" of Article 235 of the Treaty, which stipulated the use of directives and nothing else.
- With the ratification of the 1999 Amsterdam Treaty, the EU can only adopt eco-taxes and other fiscal measures with the unanimous agreement of every state (Jordan 1998). This need for unanimity represents both a huge hurdle to ecological tax reform and a continuing institutional inducement to rely on regulation.
- The founding Member States gave the EU a powerful institutional incentive to regulate wherever possible by vesting it with so few financial resources of its own. From the Commission's perspective, regulation has the benefit of being paid for by private actors in the Member States rather than the EU itself (Majone 1996).

In this study, I consider biodiversity management in three cases:

- There is no such international authority as the Commission.
- The current situation in the EU: regulation by the Commission.
- The Commission gets more authority: it can use subsidies and distribute the costs of these to the member countries.

The comparison of these cases reveals whether or not the Commission's present authority is adequate.

MacArthur and Wilson (1967) show that the total number of species is an increasing function of the habitat area. On the assumption that the number of species yields utility, Swanson (1994), Barbier and Schulz (1997) and Endres and Radke (1999) consider the optimal area of habitat, comparing the benefits of its maintenance with the opportunity cost of using land in production. These models analyze the effects of an external shock (e.g. a change in trade policy) on biodiversity. Rowthorn and Brown (1999) introduce exogenous technological change into the optimal habitat model, finding that a country with a high discount rate preserves more land when the elasticity of substitution between consumption and species exceeds unity.

Without endogenous technological change, the optimal choice of a habitat is merely that of allocating land between conservation and production. With endogenous technological change, there may be the following positive link between biodiversity and economic growth. The protection of biodiversity requires transferring land from production to conservation. If this decreases output, then employment in production and wages fall. Lower wages encourage labor-intensive R&D to expand, thus speeding up technological change and economic growth. Because this link may play an important role in the analysis, I introduce in-house R&D into the optimal habitat model.

To consider the political economy of biodiversity management, I introduce lobbying into the the optimal habitat model. This can be examined either by the *all-pay auction model* in which the lobbyist making the greater effort wins with certainty, or the *menu-auction model* in which the lobbyists announce their bids contingent on the politician's actions. In the all-pay auction model, lobbying expenditures are incurred by all the lobbyists before the politician takes an action. In the menu-auction model, it is not possible for a lobbyist to spend money and effort on lobbying without getting what he lobbied for. A good example of the all-pay auction is Johal and Ulph's environmental-policy model (2002) in which local interest groups lobby to influence the probability of getting their favorite type of government elected. I however opt for the menu-auction model, because that better characterizes the case in which the international agency's decision variables lobbied over (e.g., regulatory constraints, subsidies) are continuous and the interest groups obtain marginal improvements in their position by lobbying. I assume in this document that the international agency is self-interested, households love biodiversity, goods are produced from labor and land and biodiversity is an increasing function of habitat land in all countries of the economy.

This paper is organized as follows. Section 2 presents the structure of the economy and section 3 the model for a single country. Section 4 constructs the Pareto optimum for the economy as a reference case. Sections 5 and 6 examine the two alternatives of biodiversity management: direct regulation and conservation subsidies.

2 The model

Consider an economy with a large number of countries which are placed evenly over the limit $[0, 1]$.[1] All countries produce the same consumption good at the price p. Each country j possesses one unit of labor, of which the amount l_j is devoted to production and the rest z_j to R&D, and one unit of land, of which the amount n_j is devoted to production and the rest b_j to conservation:

$$1 = l_j + z_j, \quad 1 = n_j + b_j. \tag{1}$$

MacArthur and Wilson (1967) show empirically that the number of species expected to survive in an island is proportional to the area of that island. Following Rowthorn and Brown (1999), I assume that in each country j, the area devoted to conservation, b_j, functions like an "island" in the MacArthur-Wilson sense. Thus, *biodiversity* in the economy, b, can be specified simply

[1] If the countries were heterogeneous, then there could be multiple equilibria.

as the sum of conserved areas in the economy:

$$b \doteq \int_0^1 b_k dk. \tag{2}$$

I assume that in each country j there is a single revenue-maximizing agent (hereafter called country j) that controls all resources in that country. Its utility starting at time T is[2]

$$\int_T^\infty c_j b^\delta e^{-\rho(\theta-T)} d\theta, \quad \delta > 0, \quad \rho > 0, \tag{3}$$

where θ is time, ρ the constant rate of time preference, c_j its consumption, b biodiversity, and δ a parameter with the following characterization: the higher δ, the more the households appreciate biodiversity in the economy, b. Because there is no money in the model that would pin down the nominal price level at any time, I can choose the monetary unit so that the consumer price $(1+\tau)p$, where p is the producer price and τ is the consumption tax, is equal to the externality effect b^δ in the model:

$$(1+\tau)p = b^\delta \quad \text{or} \quad p = b^\delta/(1+\tau). \tag{4}$$

2.1 Technology

When country j develops a new technology, it increases its total factor productivity (TFP) by the constant $a > 1$. Its TFP is then equal to a^{γ_j}, where γ_j is its technology serial number. Given TFP, country j is subject to the CES production function $f(l_j, n_j)$ with constant returns to scale, where l_j (n_j) is the input of labor (land):

$$\begin{aligned} & y_j = a^{\gamma_j} f(l_j, n_j), \quad f_l > 0, \quad f_n > 0, \quad f_{ll} < 0, \quad f_{ln} = -f_{ll} l_j/n_j, \\ & f_{nn} = -f_{ln} l_j/n_j = f_{ll}(l_j/n_j)^2, \end{aligned} \tag{5}$$

[2]With the general form of the utility function, $\int_T^\infty c_j^{1-\beta} b^\delta e^{-\rho(\theta-T)} d\theta$, where $\beta \in [0,1)$ is a constant, it would be very difficult to find a stationary state in the model.

where the subscript l (n) denotes the partial derivative with respect to l_j (n_j). In this one-good economy, total consumption is equal to total production:

$$\int_0^1 c_j dj = \int_0^1 y_k dk. \tag{6}$$

Because the labor (land) market is competitive, the producer real wage (rent) w_j (r_j) is determined by the marginal product of labor (land):

$$w_j = \partial y_j/\partial l_j = a^{\gamma_j} f_l(l_j, n_j), \quad r_j = \partial y_j/\partial l_j = a^{\gamma_j} f_n(l_j, n_j). \tag{7}$$

Noting (5) and (7), the expenditure shares of land ξ and labor $1-\xi$ are

$$\frac{w_j l_j}{y_j} = \frac{l_j f_l(l_j, n_j)}{f(l_j, n_j)} = \frac{f_l(l_j/n_j, 1)}{f(l_j/n_j, 1)} = 1 - \xi\left(\frac{l_j}{n_j}\right), \quad \frac{n_j f_n(l_j, n_j)}{f(l_j, n_j)} \doteq \xi\left(\frac{l_j}{n_j}\right). \tag{8}$$

2.2 Research and development

The improvement of technology in country j depends on labor devoted to R&D in that country, z_j. In a small period of time dt, the probability that R&D will lead to development of a new technology with a jump from γ_j to $\gamma_j + 1$ is given by $\lambda z_j dt$, while the probability that R&D will remain without success is given by $1 - \lambda z_j dt$, where the constant λ is productivity in R&D. Noting (1), this defines a Poisson process χ_j with

$$d\chi_j = \begin{cases} 1 & \text{with probability } \lambda z_j dt, \\ 0 & \text{with probability } 1 - \lambda z_j dt, \end{cases} \quad z_j = 1 - l_j, \tag{9}$$

where $d\chi_j$ is the increment of the process χ_j. The expected growth rate of productivity a^{γ_j} is given by

$$g_j \doteq E\big[\log a^{\gamma_j+1} - \log a^{\gamma_j}\big] = (\log a)\lambda z_j = (\log a)\lambda(1 - l_j), \tag{10}$$

where E is the expectation operator (cf. Aghion and Howitt 1998, p. 59).

2.3 The international agency

The international agency does not observe the level of productivity, a^{γ_j}, but observes the producer real wage w_j and the producer rent r_j in each country

j. I assume that the only revenue-raising tax is the tax τ on consumption expenditure $p\int_0^1 c_k dk$, where p is the consumption price and c_k consumption in country k.[3] With a subsidy η to R&D expenditure $w_j z_j$ and a subsidy s to expenditure on conserved land, $r_j b_j$, the international agency's budget is

$$\tau \int_0^1 c_k dk = \int_0^1 (\eta w_j z_j + s r_j b_j) dj. \tag{11}$$

The international agency decides on the minimum proportion of conserved land, $\underline{b}$, for all country j:

$$b_j \geq \underline{b} \in [0,1] \text{ for } j \in [0,1]. \tag{12}$$

When this constraint is binding, the agency exercises *direct regulation*.

In order to avoid multiple equilibria, I assume that the countries are biased for a low tax rate:

Assumption 1 *If the countries face two candidates for the international agency so that both of these offer the same level of welfare for them but with a different tax rate* τ*, then they vote for the one with a lower tax rate* τ*.*

3 Countries

Country j pays political contributions R_j to the international agency. I assume, for simplicity, that the international agency consists of civil servants, of which a constant proportion $g_j \in [0,1]$ inhabits country j. It is then true that

$$\int_0^1 g_k dk = 1. \tag{13}$$

Thus, each country j gets a constant share g_j of total contributions

$$R = \int_0^1 R_k dk. \tag{14}$$

[3] This corresponds well to the institutions of the EU.

Without political contributions, country j earns output y_j and subsidies $\eta w_j z_j + sr_j b_j$ in terms of the consumption good. Given the consumption tax τ, this income is in terms of consumption equal to $(\eta w_j z_j + sr_j b_j)/(1+\tau)$. Noting (1), (5) and (7), the ratio of this 'legal' income relative to productivity, a^{γ_j}, is defined as follows:

$$
\begin{aligned}
&(y_j + \eta w_j z_j + sr_j b_j)/[(1+\tau)a^{\gamma_j}] \\
&= \big[f(l_j, n_j) + \eta z_j f_l(l_j, n_j) + s f_n(l_j, n_j) b_j\big]/(1+\tau) \\
&= \big[f(l_j, 1-b_j) + (1-l_j)\eta f_l(l_j, 1-b_j) + s f_n(l_j, 1-b_j) b_j\big]/(1+\tau) \\
&\doteq \phi(l_j, b_j, s, \eta, \tau).
\end{aligned} \tag{15}
$$

The budget constraint of country j is given by

$$
(1+\tau)pc_j = p(y_j + \eta w_j z_j + sr_j b_j) + g_j R - R_j, \tag{16}
$$

where c_j is consumption, τ the consumption tax, p the price of the consumption good, $y_j + \eta w_j z_j + sr_j b_j$ the 'legal' income, R_j the contributions to the international agency and $g_j R$ the proportion of total contributions in country j. Noting (4), (15) and (16), consumption in country j is determined by

$$
\begin{aligned}
c_j &= (y_j + \eta w_j z_j + sr_j b_j)/(1+\tau) + (g_j R - R_j)/[p(1+\tau)] \\
&= a^{\gamma_j}\phi(l_j, b_j, s, \eta, \tau) + (g_j R - R_j) b^{-\delta}.
\end{aligned} \tag{17}
$$

Noting (3) and (17), the expected utility of country j starting at time T is

$$
\begin{aligned}
\Gamma_j &= E\int_T^\infty c_j b^\delta e^{-\rho(\theta - T)} d\theta \\
&= E\int_T^\infty a^{\gamma_j}\frac{b^\delta}{1+\tau}\phi(l_j, b_j, s, \eta, \tau) e^{-\rho(\theta-T)} d\theta + \frac{g_j R - R_j}{\rho},
\end{aligned} \tag{18}
$$

where E is the expectation operator. Country j maximizes (18) by labor input l_j and conserved land b_j subject to technological change (9) and the regulatory constraint (12), taking the tax τ, the subsidies (s, η), biodiversity

b, and the contributions (R_j, R) as given. This maximization and the symmetry throughout the countries $j \in [0,1]$ imply the results (cf. Appendix A):

(i) $l_j = l$, $b_j = b$ *and* $n_j = 1 - b_j = 1 - b$ *for* $j \in [0,1]$, (19)

(ii) the equilibrium value of the function ϕ*:*

$$\phi(l, b, s, \eta, \tau) = f(l, 1-b), \tag{20}$$

(iii) the first-order condition for conserved land b_j*:*

$$(1-s)\xi\left(\frac{l}{1-b}\right) = \left[(1-l)\eta - \frac{slb}{1-b}\right]\frac{l f_{ll}(l, 1-b)}{f(l, 1-b)} \text{ for } b > \underline{b}, \tag{21}$$

(iv) the first-order condition for labor input in production, l_j*:*

$$(1-\eta)\left[1 - \xi\left(\frac{l}{1-b}\right)\right] + \left[(1-l)\eta - \frac{slb}{1-b}\right]\frac{l f_{ll}(l, 1-b)}{f(l, 1-b)}$$
$$= \frac{(a-1)\lambda l}{\rho + (1-a)\lambda(1-l)}, \tag{22}$$

(iv) the value function Γ_j*:*

$$\Gamma_j(b, \gamma_j, s, \eta, \tau, R, R_j), \quad \partial\Gamma_j/\partial R_j = -1/\rho,$$
$$\frac{\partial \Gamma_j}{\partial b} = \frac{b^{\delta-1}\Omega_j}{1+\tau}\left[\frac{b}{1-b}\left\{(s-1)\xi\left(\frac{l}{1-b}\right) + \left[(1-l)\eta - \frac{sl}{1-b}\right]\frac{l f_{ll}(l, 1-b)}{f(l, 1-b)}\right\} + \delta\right] \text{ for } b = \underline{b},$$
$$\frac{\partial \Gamma_j}{\partial b} = \frac{b^{\delta}}{1+\tau}\delta\frac{\Omega_j}{b} = \delta\frac{b^{\delta-1}\Omega_j}{1+\tau} \text{ for } b > \underline{b}, \tag{23}$$

where Ω_j is the maximum value of $E\int_T^\infty a^{\gamma_j}\phi e^{-\rho(\theta-T)}d\theta$.

4 The Pareto optimum

Assume a *benevolent* international agency that claims no political contributions, $R_j = 0$ for all j, uses subsidies (s, η) to both R&D and conserved land, and maximizes the expected value of the geometric average of the utility of the countries in the whole economy:

$$E\int_T^\infty cb^\delta e^{-\rho(\theta-T)}d\theta \quad \text{with} \quad \log c \doteq \int_0^1 \log c_j dj. \tag{24}$$

Because the agency controls the allocation of resources completely by the subsidies (s,η), it attains the Pareto optimum (l^P, b^P) (cf. Appendix B):

$$\left[1-\xi\Big(\frac{l^P}{1-b^P}\Big)\right]\left[\rho+(1-a)\lambda(1-l^P)\right] = (a-1)\lambda l^P, \tag{25}$$

$$\frac{b^P}{1-b^P}\xi\left(\frac{l^P}{1-b^P}\right) = \delta. \tag{26}$$

5 Direct regulation

Assume a *self-interested* international agency that has no budget of its own, $s=\eta=\tau=0$, controls the proportion of conserved land directly by setting $b=\underline{b}$, and maximizes the present value of the expected flow of the political contributions at time T [cf. (13)],[4]

$$E\int_T^\infty \int_0^1 R_j e^{-\rho(\theta-T)}d\theta = \frac{1}{\rho}\int_0^1 R_j dj. \tag{27}$$

In line with Grossman and Helpman (1994), I construct a common agency game as follows. First, the countries set their political contributions R_j conditional on the international agency's prospective policy b, taking total contributions R as given.[5] Second, the international agency sets b and collects the contributions. Third, the countries maximize their expected utility given

[4]This is a modification of the idea of Grossman and Helpman (1994), who assume that a policy maker's welfare is a linear function of both the political contributions and the utilities of the lobbies. This characterizes the fact that the policy maker cares about (a) its revenue from political contributions and (b) the possibility of being re-elected, which depends of the utility of the electorate (i.e. the members of the lobbies). I simplify this setup by ignoring the utilities of the lobbies. Because the policy instruments must maximize the utility of each lobby in equilibrium [cf. condition (iii) in Appendix C], the results would not change if I used Grossman and Helpman's original welfare function.

[5]The crucial point in the common agency game is that each country j can credibly commit itself to its contribution function $R_j(b)$.

the contributions R_j and R. The game is solved in reverse order: first for a country (stage 3) and then for the political equilibrium (stages 2 and 1).

With direct regulation, labor input l_j is the only instrument and (22) the only equilibrium condition for country j. Noting (12), the value function (23) and the equilibrium condition (22) for country j take the form

$$\Gamma_j(b^R, \gamma_j, 0, 0, 0, R, R_j), \tag{28}$$

$$(a-1)\lambda l^R = \left[\rho + (1-a)\lambda(1-l^R)\right]\left[1 - \xi\left(\frac{l^R}{1-b^R}\right)\right]. \tag{29}$$

The international agency maximizes the present value (27). Each country j maximizes the value of its optimal program, (28), by influencing the international agency by its contributions R_j, but taking total contributions R as given. Because b^R is a policy and $R_j(b^R)$ the strategy of country j, the equilibrium conditions of this game are [cf. (*ii*) and (*iii*) in Appendix C]

$$b = \arg\max_{b^R} \frac{1}{\rho}\int_0^1 R_j(b^R)dj = \arg\max_{b^R} \int_0^1 R_j(b^R)dj, \tag{30}$$

$$b = \arg\max_{b^R} \Gamma_j(b^R, \gamma_j, 0, 0, 0, R, R_j(b^R)) \text{ for } j \in [0,1]. \tag{31}$$

With (23) and $\eta = s = \tau = 0$, the condition (31) is equivalent to

$$0 = \frac{\partial \Gamma_j}{\partial b} + \frac{\partial \Gamma_j}{\partial R_j}R_j' = (b^R)^{\delta-1}\Omega_j\left[-\frac{b^R}{1-b^R}\xi\left(\frac{l^R}{1-b^R}\right) + \delta\right] - \frac{1}{\rho}R_j'$$

and

$$R_j' = \rho(b^R)^{\delta-1}\Omega_j\left[\delta - \frac{b^R}{1-b^R}\xi\left(\frac{l^R}{1-b^R}\right)\right]. \tag{32}$$

Finally, given (32), the condition (30) is equivalent to

$$0 = \frac{1}{\rho}\int_0^1 R_j' dj = \left[\delta - \frac{b^R}{1-b^R}\xi\left(\frac{l^R}{1-b^R}\right)\right](b^R)^{\delta-1}\int_0^1 \Omega_j dj. \tag{33}$$

This and the equation (29) satisfy the conditions (25) and (26). I conclude:

Proposition 1 *Direct regulation is Pareto optimal,* $(l^R, b^R) = (l^P, b^P)$.

The international agency, benevolent or self-interested, eliminates the externality due to biodiversity as a macroeconomic decision-maker.

6 Conservation subsidies

Assume a self-interested international agency that imposes the conservation subsidy s. Assume furthermore that because the agency cannot fully distinguish between R&D and other labor expenditures, the R&D subsidy η is incentive incompatible. Without losing any generality, I can then choose $\eta = 0$.

In this common agency game, the subsidy s is a public policy instrument. With $\eta = 0$, the value function (23) and the equilibrium conditions (21) and (22) for country j become

$$\Gamma_j(b^S, \gamma_j, s, 0, \tau, R, R_j), \tag{34}$$

$$s\frac{(l^S)^2 b^S f_{ll}(l^S, 1-b^S)}{(1-b^S)f(l^S, 1-b^S)} = (s-1)\xi\left(\frac{l^S}{1-b^S}\right), \tag{35}$$

$$\frac{(a-1)\lambda l^S}{\rho + (1-a)\lambda(1-l^S)} = 1 - \xi - \frac{s(l^S)^2 f_{ll}}{(1-b^S)f} = 1 - s\xi\left(\frac{l^S}{1-b^S}\right). \tag{36}$$

In this setup, the budget constraint (11) becomes (cf. Appendix D)

$$\tau = \frac{sb^S}{1-b^S}\xi\left(\frac{l^S}{1-b^S}\right). \tag{37}$$

In the three equations (35), (36) and (37), there are three unknown variables τ, l^S and b^S, and one known variable s. This system defines the functions

$$\tau(s), \quad l^S(s), \quad b^S(s). \tag{38}$$

Unfortunately, the derivatives of these functions are mathematically ambiguous. For this reason, I make the plausible assumption that the direct effect of the subsidy s dominates. This implies that the following holds true:

Assumption 2 *An increase in the subsidy s to conserved land increases both the supply of conserved land, $(b^S)' > 0$, and the tax that is needed for financing the increase of the subsidy, $\tau' > 0$.*

The international agency maximizes the present value of the expected flow of the political contributions at time T, (27). Country j maximizes the value of its optimal program, (34), by influencing the international agency by its contributions R_j, but taking total contributions R as given. Because s is a policy and $R_j(s)$ the strategy of country j, then, given (38), the equilibrium conditions are [cf. (*ii*) and *iii*) in Appendix C]:

$$s = \arg\max_s \frac{1}{\rho}\int_0^1 R_j(s)dj = \arg\max_s \int_0^1 R_j(s)dj, \tag{39}$$

$$s = \arg\max_s \Gamma_j\big(b, \gamma_j, s, 0, \tau(s), R, R_j(s)\big) \text{ for } j \in [0,1]. \tag{40}$$

From (5), (8) and (35) it follows that conserved land is subsidized:

$$s = \Bigg[\underbrace{\xi}_{+} - \underbrace{\frac{(l^S)^2 b^S f_{ll}}{(1-b^S)f}}_{-}\Bigg]^{-1} \underbrace{\xi}_{+} > 0.$$

Given (37), this subsidy $s > 0$ must be financed by the wage tax $\tau > 0$. To show that $(l^S, b^S) \neq (l^P, b^P)$, assume $(l^S, b^S) = (l^P, b^P)$. In that case, relations (25), (36) and (38) lead to the following contradiction:

$$0 = 1 - \xi\left(\frac{l^P}{1-b^P}\right) - \frac{(a-1)\lambda l^P}{\rho + (1-a)\lambda(1-l^P)} =$$

$$1 - \xi\left(\frac{l^S}{1-b^S}\right) - \frac{(a-1)\lambda l^S}{\rho + (1-a)\lambda(1-l^S)} = \frac{sl^S}{1-b^S}\frac{l^S f_{ll}(l^S, 1-b^S)}{f(l^S, 1-b^S)} \neq 0.$$

Thus, $(l^S, b^S) \neq (l^P, b^P)$ holds true. This and Proposition 1 imply that:

Proposition 2 *The equilibrium with conservation subsidies is Pareto suboptimal,* $(l^S, b^S) \neq (l^P, b^P)$*. Consequently, a switch from regulation to conservation subsidies decreases welfare.*

This is because the international agency imposes a distorting consumption tax τ to finance the conservation subsidy s. With direct regulation, there is no distorting taxation.

Because the equilibrium (l^S, b^S) is Pareto suboptimal, then the same welfare can be attained by two tax rates τ (with corresponding subsidies s):

- With the higher tax rate τ, the subsidy s is higher and consequently, the amount of conserved land is bigger than at Pareto optimum, $b^S > b^P$.
- With the lower tax rate τ, the subsidy s is lower and consequently, the amount of conserved land is smaller than at Pareto optimum, $b^S < b^P$.

Given Assumption 1, only the equilibrium with a lower tax rate, $b^S < b^P$, is feasible. Given this, Assumption 2 and Proposition 2, I conclude:

Proposition 3 *A switch from direct regulation into conservation subsidies decreases both the growth rate (i.e. $g^R = g^P > g^S$) and biodiversity in each country (i.e. $b^R = b^P > b^S$).*

Because any inefficiency decreases the resources of the economy, there are less resources to be put into R&D and the conservation of biodiversity.

7 Conclusions

This paper considers an economy in which the conservation of land yields utility through biodiversity, firms improve their efficiency by in-house R&D and local interest groups lobby a self-interested international agency over biodiversity management. I compare two policy alternatives: the regulation of land use and subsidies for conserved land. The main findings are the following.

In the case of direct regulation, the international agency determines the use of land throughout the whole economy, fully internalizing the externality through biodiversity. In the case of conservation subsidies, revenue-raising taxes cause distortions. For this reason, a shift from subsidies to direct regulation increases the resources of the countries, promoting investment in R&D and economic growth. The transfer of labor from production to R&D decreases the demand for land in production. This promotes the conservation of land and biodiversity.

While a great deal of caution should be exercised when a highly stylized game-theoretical model is used to derive results on growth and biodiversity, the following conclusion seems to be justified. The prospect of lobbying changes the outcome of biodiversity management fundamentally. A larger package of policy instruments leads to Pareto improvement with a benevolent international agency, but to Pareto worsening with a self-interested one. In the case of Natura 2000, for instance, regulation without any budget may be an appropriate degree of authority for the Commission. Greater authority narrows biodiversity and slows down economic growth.

Appendix

A Equations (21) and (22) and function (23)

Noting (5) and (8), the function (15) has the partial derivatives:

$$\begin{aligned}\frac{\partial \phi}{\partial b_j} &= (s-1)f_n(l_j, 1-b_j) - (1-l_j)\eta f_{ln}(l_j, 1-b_j) - s f_{nn}(l_j, 1-b_j) b_j \\ &= \left\{(s-1)\xi\left(\frac{l_j}{1-b_j}\right) + \left[(1-l_j)\eta - \frac{s l_j b_j}{1-b_j}\right]\frac{l_j f_{ll}(l_j, 1-b_j)}{f(l_j, 1-b_j)}\right\} \\ &\quad \times \frac{f(l_j, 1-b_j)}{1-b_j} = 0 \ \text{ for } b > \underline{b},\end{aligned} \tag{41}$$

$$\begin{aligned}\frac{\partial \phi}{\partial l_j} &= (1-\eta) f_l(l_j, 1-b_j) + (1-l_j)\eta f_{ll}(l_j, 1-b_j) + s f_{ln}(l_j, 1-b_j) b_j \\ &= (1-\eta)\left[1 - \xi\left(\frac{l_j}{1-b_j}\right)\right]\frac{f(l_j, 1-b_j)}{l_j} \\ &\quad + \left[(1-l_j)\eta - \frac{s l_j b_j}{1-b_j}\right] f_{ll}(l_j, 1-b_j).\end{aligned} \tag{42}$$

The maximization of the expected utility (18) by (l_j, b_j) s.t. (9) and (12), given $(\tau, s, \eta, b, R_j, R)$, is equivalent to the maximization of

$$E\int_T^\infty a^{\gamma_j}\frac{b^\delta}{1+\tau}\phi(l_j, b_j, s, \eta, \tau)e^{-\rho(\theta - T)}d\theta$$

s.t. (9) and (12), given $(\tau, s, \eta, b, R_j, R)$. The value of this optimal program starting at time T is

$$\Omega_j(\gamma_j, \underline{b}, s, \eta, \tau) \doteq \max_{(l_j, b_j) \text{ s.t. } (9),(12)} E \int_T^\infty \frac{b^\delta}{1+\tau} a^{\gamma_j} \phi(l_j, b_j, s, \eta, \tau) e^{-\rho(\theta - T)} d\theta. \tag{43}$$

The Bellman equation corresponding to the optimal program (43) is given by (cf. Dixit and Pindyck 1994)

$$\rho \Omega_j = \max_{(l_j, b_j) \text{ s.t. } (9)} \Lambda^j(l_j, b_j, \gamma_j, \underline{b}, s, \eta, \tau), \tag{44}$$

where

$$\Lambda^j(l_j, b_j, \gamma_j, \underline{b}, s, \eta, \tau) =$$
$$\frac{b^\delta}{1+\tau} a^{\gamma_j} \phi(l_j, b_j, s, \eta, \tau) + \lambda(1 - l_j)\left[\Omega_j(\gamma_j + 1, \underline{b}, s, \eta, \tau) - \Omega_j(\gamma_j, \underline{b}, s, \eta, \tau)\right]. \tag{45}$$

The first-order conditions corresponding to the Bellman equation (44) and (45) are $\partial \Lambda^j / \partial l_j = 0$ and $\partial \Lambda^j / \partial b_j = 0$. To solve the dynamic program, I assume that the value of the program, Ω_j, is in fixed proportion to the instantaneous utility at the optimum:

$$\Omega_j(\gamma_j, \underline{b}, s, \eta, \tau) = \varphi_j \frac{b^\delta}{1+\tau} a^{\gamma_j} \phi(l_j^*, b_j, s, \eta, \tau) \text{ with } b_j = b_j^* \text{ for } b_j > \underline{b}, \tag{46}$$

where φ_j is a constant and l_j^* and b_j^* are the optimal values of l_j and b_j. From (46) it follows that

$$\Omega_j(\gamma_j + 1, \underline{b}, s, \eta, \tau) / \Omega_j(\gamma_j, \underline{b}, s, \eta, \tau) = a. \tag{47}$$

Inserting (46) and (47) into the Bellman equation (44) and (45) yields

$$1/\varphi_j = \rho + (1 - a)\lambda(1 - l_j) > 0. \tag{48}$$

Noting (41), (42), (45), (47) and (48), the first-order conditions corresponding to the maximization (44) are given by

$$\frac{1}{\Omega_j} \frac{\partial \Lambda^j}{\partial b_j} = \frac{b^\delta a^{\gamma_j}}{\Omega_j} \frac{\partial \phi}{\partial b_j} = \frac{b^\delta a^{\gamma_j}}{(1+\tau)\Omega_j} \frac{f(l_j, 1 - b_j)}{1 - b_j} \left\{ (s-1)\xi\left(\frac{l_j}{1 - b_j}\right) \right.$$
$$\left. + \left[(1 - l_j)\eta - \frac{s l_j}{1 - b_j}\right] \frac{l_j f_{ll}(l_j, 1 - b_j)}{f(l_j, 1 - b_j)} \right\} = 0 \text{ for } b > \underline{b}, \tag{49}$$

$$
\begin{aligned}
\frac{1}{\Omega_j}\frac{\partial \Lambda^j}{\partial l_j} &= \frac{b^\delta a^{\gamma_j}}{(1+\tau)\Omega_j}\frac{\partial \phi}{\partial l_j} - \lambda\left[\frac{\Omega_j(\gamma_j+1,\underline{b},s,\eta,\tau)}{\Omega_j(\gamma_j,\underline{b},s,\eta,\tau)} - 1\right] = \frac{1}{\varphi_j \phi}\frac{\partial \phi}{\partial l_j} - (a-1)\lambda \\
&= \big[\rho + (1-a)\lambda(1-l_j)\big]\frac{1}{\phi}\frac{\partial \phi}{\partial l_j} - (a-1)\lambda \\
&= \big[\rho + (1-a)\lambda(1-l_j)\big]\frac{f(l_j,1-b_j)}{(1+\tau)\phi}\left\{(1-\eta)\left[1-\xi\left(\frac{l_j}{1-b_j}\right)\right]\frac{1}{l_j}\right. \\
&\quad \left. + \left[(1-l_j)\eta - \frac{s l_j b_j}{1-b_j}\right]\frac{f_{ll}(l_j,1-b_j)}{f(l_j,1-b_j)}\right\} - (a-1)\lambda = 0. \qquad (50)
\end{aligned}
$$

In the system consisting of the international agency budget (11) and the first-order conditions (49) and (50) for all countries $j \in [0,1]$, there is symmetry throughout $j \in [0,1]$. This implies $l_j = l$ and $b_j = b$ for $j \in [0,1]$. From this, (1), (5), (6), (13), (14), (15) and (17) it follows that

$$
\begin{aligned}
\phi(l,b,s,\eta,\tau) &= \int_0^1 a^{\gamma_j}\phi(l,b,s,\eta,\tau)dj \Big/ \int_0^1 a^{\gamma_k}dk \\
&= \left[\int_0^1 a^{\gamma_j}\phi(l,b,s,\eta,\tau)dj + b^{-\delta}\underbrace{\int_0^1 (g_j R - R_j)dj}_{=0}\right] \Big/ \int_0^1 a^{\gamma_k}dk \\
&= \int_0^1 \big[a^{\gamma_j}\phi(l,b,s,\eta,\tau) + (g_j R - R_j)b^{-\delta}\big]dj \Big/ \int_0^1 a^{\gamma_k}dk \\
&= \int_0^1 c_j dj \Big/ \int_0^1 a^{\gamma_k}dk = \int_0^1 y_j dj \Big/ \int_0^1 a^{\gamma_k}dk = f(l,1-b).
\end{aligned} \qquad (51)
$$

This implies (20). Inserting (51), $l_j = l$ and $b_j = b$ back to (49) and (50) yields (21) and (22).

Noting $l_j = l$, $b_j = b$, (15), (43), (46) and (51), the expected utility of country j, (18), can be written as follows:

$$
\Gamma_j(b,\gamma_j,\underline{b},s,\eta,\tau,R,R_j) \doteq \Omega_j(\gamma_j,\underline{b},s,\eta,\tau) + (g_j R - R_j)/\rho, \quad \frac{\partial \Gamma_j}{\partial R_j} = -\frac{1}{\rho},
$$

$$
\begin{aligned}
\frac{\partial \Gamma_j}{\partial \underline{b}}\bigg|_{b=\underline{b}} &= \frac{b^\delta}{1+\tau}\left[\frac{\partial \Omega_j}{\partial b_j} + \delta\frac{\Omega_j}{b}\right] = \frac{b^\delta}{1+\tau}\left[\frac{\Omega_j}{\phi}\frac{\partial \phi}{\partial b_j} + \delta\frac{\Omega_j}{b}\right] \\
&= \frac{b^\delta}{1+\tau}\left\{\frac{\Omega_j}{\phi}\big[(s-1)f_n - (1-l_j)\eta f_{ln} - s f_{nn}\big] + \delta\frac{\Omega_j}{b}\right\} \\
&= \frac{b^\delta \Omega_j}{1+\tau}\left[\frac{1}{\phi}\left\{(s-1)\frac{f(l_j,1-b_j)}{1-b_j}\xi + \left[(1-l)\eta - \frac{sl}{1-b}\right]\frac{l f_{ll}}{1-b}\right\} + \frac{\delta}{b}\right]
\end{aligned}
$$

$$= \frac{b^{\delta}\Omega_j}{1+\tau}\left[\frac{f(l,1-b)}{(1-b)\phi(l,b,s,\eta,\tau)}\left\{(s-1)\xi + \left[(1-l)\eta - \frac{slb}{1-b}\right]\frac{lf_{ll}}{f}\right\} + \frac{\delta}{b}\right]$$

$$= \frac{b^{\delta-1}\Omega_j}{1+\tau}\left[\frac{b}{1-b}\left\{(s-1)\xi\left(\frac{l}{1-b}\right) + \left[(1-l)\eta - \frac{slb}{1-b}\right]\frac{lf_{ll}(l,1-b)}{f(l,1-b)}\right\} + \delta\right],$$

$$\frac{\partial\Gamma_j}{\partial b} = \frac{b^{\delta}}{1+\tau}\delta\frac{\Omega_j}{b} = \delta\frac{b^{\delta-1}\Omega_j}{1+\tau} \text{ for } b > \underline{b}.$$

B Equations (25) and (26)

The average serial number of technology in the economy is given by

$$\gamma = \int_0^1 \gamma_j dj. \tag{52}$$

Given the Poisson property of the improvement of technology in countries $j \in [0,1]$ (cf. Subsection 2.2), one obtains the following. In a small period of time dt, the probability that R&D will lead a jump from γ to $\gamma+1$ is given by $\lambda z\, dt$, while the probability that R&D will remain without success is given by $1-\lambda z\, dt$. Noting (9), this defines a Poisson process χ with

$$d\chi = \begin{cases} 1 & \text{with probability } \lambda(1-l)dt, \\ 0 & \text{with probability } 1-\lambda(1-l)dt, \end{cases} \qquad l \doteq \int_0^1 l_j dj, \tag{53}$$

where $d\chi$ is the increment of the process χ.

Because there is perfect symmetry throughout countries $j \in [0,1]$ in the system (2), (53), (21) and (22), there is $l_j = l = l^P$ and $b_j = b = b^P$ for $j \in [0,1]$ in equilibrium. Because there is one-to-one correspondence from (η, s) to (l^P, b^P), one can replace the subsidies (η, s) by (l^P, b^P) as the international agency's policy instruments. Thus, the international agency maximizes (24) by (l^P, b^P) s.t. technological change (53). Noting (5), (17) and (52), one obtains the value function of this maximization as follows:

$$\Delta(l^P, b^P) \doteq E\int_T^{\infty} cb^{\delta}e^{-\rho(\theta-T)}d\theta = f(l^P, 1-b^P)(b^P)^{\delta}E\int_T^{\infty} a^{\gamma}e^{-\rho(\theta-T)}d\theta$$
$$= \frac{f(l^P, 1-b^P)(b^P)^{\delta}}{\rho+(1-a)\lambda l^P}.$$

Noting (8), this leads to the first-order conditions

$$\frac{\partial \log \Delta}{\partial l^P} = \frac{f_l(l^P, 1-b^P)}{f(l^P, 1-b^P)} + \frac{(1-a)\lambda}{\rho + (1-a)\lambda l^P}$$
$$= \frac{1}{l^P}\left[1 - \xi\left(\frac{l^P}{b^P}\right)\right] + \frac{(1-a)\lambda}{\rho + (1-a)\lambda l^P} = 0,$$
$$\frac{\partial \log \Delta}{\partial l^P} = \frac{\delta}{b^P} - \frac{f_m(l^P, 1-b^P)}{f(l^P, 1-b^P)} = \frac{\delta}{b^P} - \frac{1}{1-b^P}\xi\left(\frac{l^P}{b^P}\right) = 0.$$

These equations imply (25) and (26).

C The lobbying game

Following Dixit, Grossman and Helpman (1997), a subgame perfect Nash equilibrium for this game is a policy ζ and a set of contribution schedules $R_1(\zeta), ..., R_J(\zeta)$ such that the following conditions $(i) - (iv)$ hold:

(i) Contributions R_j are non-negative but no more than the contributor's income, $\Gamma_j \geq 0$.

(ii) The policy ζ maximizes the international agency's welfare (27) taking the contribution schedules R_j as given.

(iii) Country j cannot have a viable strategy $R_j(\zeta)$ that yields it a higher level of utility than in equilibrium, given the others' contributions.

(iv) Country j provides the international agency at least with the level of utility as in the case in which it offers nothing ($R_j = 0$), and the international agency responds optimally given the contribution functions of the other countries.

D Equation (37)

Given $\eta = 0$, (7), (8), (13), (14), (17), (19) and (20), the international agency budget constraint (11) becomes

$$\tau = \frac{\int_0^1 (\eta w_j z_j + s r_j b_j) dj}{\int_0^1 c_k dk} = \frac{s \int_0^1 r_j b_j dj}{\int_0^1 c_k dk} = \frac{s \int_0^1 a^{\gamma_j} f_n(l_j, n_j) b_j dj}{\int_0^1 c_k dk}$$

$$= \frac{s \int_0^1 a^{\gamma_j} f_n(l_j, n_j) b_j dj}{\int_0^1 a^{\gamma_k} \phi(l_k, b_k, s, \eta, \tau) dk + \underbrace{\int_0^1 (g_k R - R_k) b^{-\delta} dk}_{=0}} = \frac{s \int_0^1 a^{\gamma_j} f_n(l_j, n_j) b_j dj}{\int_0^1 a^{\gamma_k} \phi(l_k, b_k, s, \eta, \tau) dk}$$

$$= s \frac{f_n(l^S, 1 - b^S) b^S}{\phi(l^S, b^S, s, 0, \tau)} = s \frac{f_n(l^S, 1 - b^S) b^S}{f(l^S, 1 - b^S)} = \frac{s b^S}{1 - b^S} \xi \left(\frac{l^S}{1 - b^S} \right).$$

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