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Abstract: In this paper we investigate the reasons why integrated conservation and development projects (ICDPs) fail to achieve their conservation goals. We develop a bio-economic model of open access land and wildlife exploitation, which is consistent with many farming and hunting societies living in close proximity to forest reserves in developing countries. We show that the ICDP creates incentives to conserve habitat and wildlife, but, in general, the socially optimal level of conservation cannot be achieved, because of externalities among the local communities. We show how a social planner can achieve the socially optimal levels of habitat and wildlife by a more encompassing tax/subsidy regime.

Keywords: bio-economic modelling, competing land-use, ecotourism, integrated conservation and development projects, poaching, wildlife and habitat conservation

JEL-Classification: Q56, O13, H23

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1 Introduction

In developing countries protected areas often fail to achieve their aim of protecting natural habitats and endangered animal species (e.g. Barrett and Arcese 1995, Gibson and Marks 1995, Swanson and Barbier 1992). The reason is that they often act directly against the economic interests of the local population, which is excluded from land and wildlife utilization to which it formerly had access. In addition, the protection of many natural reserves is poorly enforced, because of the vast areas involved and the poor financial situation of the park management (e.g. Kiss 1990). As a consequence, illegal land and wildlife utilization, such as slashing and burning forests for agricultural use and hunting game animals for meat, are widespread.

Recently, these shortcomings of the traditional approach to protected area management resulted in the implementation of so-called "integrated conservation and development projects" (ICDPs). In theory, the ICDP overcomes the open access problem by coupling conservation and development activities. The development activity creates revenues which are used to create incentives for the local population to engage in conservation activities. Thus, the successful ICDP results in a "win-win" situation in which (i) natural habitats and wildlife are protected, and (ii) the income of the local population is increased, and poverty and hardship are alleviated. In practice, however, many ICDPs have failed (or are likely to fail) to achieve their conservation goals. The literature on ICDPs identifies two main reasons for their failure. First, ICDPs may give *wrong* incentives (e.g. Wells et al. 1992, Ferraro 2001, Ferraro and Kiss 2002). For example, local people do not voluntarily refrain from poaching if they receive lumpsum transfers, as new income sources are complements to existing activities rather than substitutes. Second, ICDPs may give *too little* incentives. In fact, there is ample evidence that only a small fraction of the ICDPs' revenues reach the local communities and, thus, incentives for the local population to change habits are small (e.g. Barrett and Arcese 1995, Bookbinder et al. 1998, Gibson and Marks 1995, Wells et al. 1992).

The aim of this paper is to investigate in a theoretical model the reasons for benefit-sharing ICDPs to fail. As a prime example for an ICDP, which has gained a lot of interest among both scholars and practitioners, we consider a *non-invasive ecotourism enterprise* (e.g. Goodwin 1996, Isaacs 2000). We develop a bio-economic model of local subsistence farming and hunting communities living on a fixed size of land. In its pristine state it is the habitat of a native animal species, which can be hunted for game meat. In addition, the land can be turned into agricultural land, which yields crop production. The state is supposed to be unable to enforce property rights on both land and wildlife. Thus, the local communities face de facto an open access regime. Due to the public good property of both land and wildlife, the actions of each community impose negative externalities on all other communities, which are not taken into account by the individual communities when they decide about the size of farmland to cultivate and how to distribute a fixed labor endowment between farmland cultivation and hunting. In addition, there is a state owned enterprise which earns and distributes revenues from ecotourism that depend on the abundance of wildlife.

Our contribution to the ICDP literature is twofold. First, we show that even well designed and strong incentives (i.e. distributing all ecotourism revenues to the local population) lead to lower levels of habitat and wildlife conservation compared to the social optimum. This is because the public good property of both habitat and wildlife causes two negative externalities which cannot be internalized by just one policy lever. Second, we show how a tax/subsidy scheme can be designed that implements the social optimum. The main problem for such a scheme is that certain actions, such as poaching, cannot be observed, and thus can neither be taxed nor subsidized. In fact, our solution to achieve the optimal levels of wildlife and habitat conservation disentangles the conservation and the development goal. While the ecotourism enterprise determines the optimal levels of habitat and wildlife conservation, their implementation is achieved by a self-financing tax/subsidy scheme, which itself is viable without the ecotourism revenues.

Our model differs from the existing theoretical literature on the effects of ICDPs in two key elements. First, while Barrett and Arcese (1998), Johannesen and Skonhoft (2005), and Skonhoft and Solstad (1998), among others, concentrate on the competition in wildlife harvest between the locals and the reserve management, we focus attention to the problem of habitat loss and wildlife exploitation due to externalities, which stem from the public good property of land and wildlife. Second, in our model the native animal species is confined to the natural habitat. As a consequence, we abstract from the nuisance argument for poaching that wandering animal herds interfere with agricultural production (e.g. Johannesen and Skonhoft 2005, Bulte and Rondeau forthcoming, Rondeau and Bulte forthcoming). While models which emphasize the nuisance argument for poaching better fit to rangeland reserves and large mammal species, our model is compatible with forest reserves and small mammal or bird species, which crucially depend on the forest for shelter, food and reproduction (e.g. Bookbinder et al. 1998, Naidoo and Adamowicz 2005). In fact, our bio-economic model is most closely related to Smith (1975) and Bulte and Horan (2003), who consider pressure on wildlife conservation due to hunting and habitat loss. However, they concentrate on the dynamic development of a subsistence farming and hunter society in an open access regime, but do not consider nature and wildlife conservation by ICDP schemes.

The paper is structured as follows. In section 2 we introduce the bio-economic model. The optimal bio-economic equilibrium is derived in section 3. In section 4 we investigate how different decentralized regimes deviate from the social optimum. Therefore, we first develop a generic decentralized model (section 4.1), then we analyze the outcomes of a laissez faire open access economy (section 4.2) and of a decentralized economy with sharing ecotourism revenues (section 4.3). As the ICDP case falls short of the social optimum, we introduce a more encompassing tax/subsidy regime in section 4.4. Section 5 discusses model assumptions with respect to our results and concludes. The proofs of all propositions are given in the Appendix.

2 A simple bio-economic model

Consider an area of land of fixed size 1, which is split into a homogeneous area of wood W and a homogeneous area of farmland F, and thus $F + W = 1$. The wood W is the habitat of a native animal species bird B. The area of land is also home to n identical local communities. In line with traditional reasoning, the elders of each community are supposed to decide over the community's actions (Marks 1984). Hence, we abstract from conflicting interests *within* the communities, but in contrast to most of the existing literature on ICDPs, which assumes the local population to be one homogeneous group, we consider the externalities that the actions of one community might impose on *other* communities. Each community is supposed to act such that it maximizes its own welfare, where the welfare of community i is given by a welfare function V, which solely depends on the consumption c_i of community i and satisfies standard curvature properties ($V' > 0$, $V'' < 0$). Thus, we abstract from an explicit valuation of the levels of both habitat W and bird population B. Each community i decides about the amount of land f_i, which is used as farmland. Thus, the total size of farmland is given by $F = \sum_{i=1}^{n} f_i$. In addition, each community commands a fixed labor endowment normalized to 1, which is distributed between farmland cultivation and hunting bird. As all communities are supposed to be identical, they all use identical technologies for farmland cultivation and hunting.

Farmland can be cultivated to produce consumption according to the following Cobb-

Douglas production function P:

$$P(f_i, l_i) = \alpha_1 f_i^{\beta} l_i^{1-\beta} \ , \qquad \alpha_1 > 0 \ , \quad 0 < \beta < 1 \ , \tag{1}$$

where l_i is the amount of labor community i assigns to crop production, α_1 is a scaling factor for the overall productivity of farming, and β and $1 - \beta$ are the production elasticities of farmland and labor in the cultivation of farmland. Thus, crop production P depends positively on the levels of farmland f_i and labor input l_i ($P_{f_i} > 0$, $P_{l_i} > 0$) and exhibits constant returns to scale.[1]

In addition, communities can produce consumption by hunting bird via a Gordon-Schäfer production function H, which depends positively on both the bird population B and the amount of labor assigned to hunting $1 - l_i$[2] ($H_B > 0$, $H_{l_i} < 0$), and exhibits constant returns to scale with respect to labor

$$H(B, l_i) = \alpha_2 B \left(1 - l_i\right) \ , \qquad \alpha_2 > 0 \ , \tag{2}$$

where α_2 is a scaling factor for the overall productivity of hunting.

Finally, consumption can be generated by a state managed ecotourism enterprise. We consider a non-invasive form of ecotourism, where the prime incentive for tourists to engage in ecotourism activities is the excitement of visiting pristine wildlife environments (e.g. Goodwin 1996, Naidoo and Adamowicz 2005). Thus, total ecotourism revenues are assumed to depend on the abundance of bird B

$$E(B) = \alpha_3 B^{\gamma} \ , \qquad \alpha_3 > 0 \ , \quad 0 < \gamma \leq \frac{1}{2} \ , \tag{3}$$

where α_3 is a scaling factor for the overall productivity of ecotourism, and γ is the production elasticity of bird in creating ecotourism revenues. We impose $\gamma \leq \frac{1}{2}$ to ensure that ecotourism exhibits non-increasing economies of scale in the bio-economic equilibrium (as B itself depends on the level of wood W).

The bird population reproduces according to the reproduction function R and is re-

[1] Throughout the paper derivatives of functions which solely depend on one variable will be denoted by primes, and partial derivatives of functions with more than one variable by subscripts: $\frac{dZ(x)}{dx} = Z'(x)$, $\frac{d^2Z(x)}{dx^2} = Z''(x)$, $\frac{\partial Z(x_1,\ldots,x_n)}{\partial x_i} = Z_{x_i}$, $\frac{\partial^2 Z(x_1,\ldots,x_n)}{\partial x_i \partial x_j} = Z_{x_i x_j}$.

[2] As consumption (and, thus, welfare) can always be increased by assigning additional labor to the cultivation of farmland, the labor restriction holds with equality in the optimum.

duced by the total amount of hunting $\sum_{i=1}^{n} H(B, l_i)$

$$\frac{dB}{dt} = R(B, W) - \sum_{i=1}^{n} H(B, l_i) \ . \tag{4}$$

The reproduction function R is supposed to be a logistic growth function, which depends on the size of the bird population B and the size of the bird habitat wood W

$$R(B, W) = \epsilon\, B \left[1 - \frac{B}{W}\right] \ , \qquad \epsilon > 0 \ , \tag{5}$$

where ϵ measures the reproduction capabilities of bird. The maximal level of bird is given by the habitat size W. Thus, the level of wood determines the *carrying capacity* for the bird population.

For the sake of a tractable model, we do not consider population growth. Thus, the number of individuals within each community and the number of communities n is constant. Moreover, we abstract from transitional dynamics and assume a bio-economic equilibrium, i.e. $\frac{dB}{dt} = 0$, which implies

$$R(B, W) = \epsilon\, B \left[1 - \frac{B}{W}\right] = \alpha_2 B \sum_{i=1}^{n} (1 - l_i) = \sum_{i=1}^{n} H(B, l_i) \ . \tag{6}$$

Solving equation (6) for the bird population B yields:

$$B = \left[1 - \frac{\alpha_2}{\epsilon} \sum_{i=1}^{n} (1 - l_i)\right] W \ . \tag{7}$$

Taking further into account that

$$W = 1 - \sum_{i=1}^{n} f_i \ , \tag{8}$$

we see that the bio-economic equilibrium is completely determined by the communities' choices of f_i and l_i.

3 Farming, hunting and wildlife conservation in the social optimum

Both the habitat size W and the wildlife population B exhibit public good properties. The bird population directly affects hunting and ecotourism revenues. As the reproduction of the bird population depends on the carrying capacity, the habitat size indirectly affects both the success of hunting and the ecotourism revenues. Thus, the communities' individual choices of f_i and l_i impose externalities on all other communities which are not taken into account by the individually maximizing communities. As a consequence, the decentralized bio-economic equilibrium in which all communities maximize their welfare individually, generally falls short of the Pareto optimal outcome. Before we discuss the decentralized solution in the next section, we derive the socially optimal outcome, which is an important benchmark to evaluate the performance of different conservation policies.

Consider a social planner, who seeks to maximize the sum of welfare of all communities in the bioeconomic equilibrium.[3] We assume that all ecotourism revenues are equally distributed among the communities. Thus, the consumption c_i of community i is given by:

$$c_i = P(f_i, l_i) + H(B, l_i) + \frac{1}{n}E(B) \ , \qquad i = 1, \ldots, n \ . \tag{9}$$

Then, the social planner's problem is

$$\max_{\{f_i\}_{i=1}^n, \{l_i\}_{i=1}^n} \sum_{i=1}^{n} V(c_i) \ , \tag{10}$$

subject to equations (7), (8), (9), and the inequality constraints

$$0 \leq 1 - l_i \ , \qquad i = 1, \ldots, n \ . \tag{11}$$

Denoting the Lagrange multipliers for the equality constraints (7), (8) and (9) by λ_B, λ_W and λ_{c_i}, and the Kuhn-Tucker parameter for the inequality constraints (11) by μ_{l_i}, we derive the following Lagrangian $\mathcal{L}$:

$$\begin{aligned} \mathcal{L} \ &= \ \sum_{i=1}^{n} \left\{ V(c_i) + \lambda_{c_i} \left[P(f_i, l_i) + H(B, l_i) + \frac{1}{n}E(B) - c_i \right] + \mu_{l_i}(1 - l_i) \right\} \\ &+ \ \lambda_B \left\{ \left[1 - \frac{\alpha_2}{\epsilon} \sum_{i=1}^{n} (1 - l_i) \right] W - B \right\} + \lambda_W \left(1 - \sum_{i=1}^{n} f_i - W \right) \ . \end{aligned} \tag{12}$$

[3] As all communities are identical, maximizing the sum of welfare of all communities is equivalent to maximizing the welfare of a representative community.

The first-order conditions for an optimal solution are

$$\frac{\partial \mathcal{L}}{\partial c_i} = V'(c_i) - \lambda_{c_i} = 0 , \quad i = 1, \ldots, n , \tag{13a}$$

$$\frac{\partial \mathcal{L}}{\partial f_i} = \lambda_{c_i} P_{f_i}(f_i, l_i) - \lambda_W = 0 , \quad i = 1, \ldots, n , \tag{13b}$$

$$\frac{\partial \mathcal{L}}{\partial l_i} = \lambda_{c_i} \left[P_{l_i}(f_i, l_i) + H_{l_i}(B, l_i) \right] + \frac{\alpha_2}{\epsilon} W \lambda_B - \mu_{l_i} = 0 , \quad i = 1, \ldots, n , \tag{13c}$$

$$\frac{\partial \mathcal{L}}{\partial B} = \sum_{i=1}^{n} \lambda_{c_i} \left[H_B(B, l_i) + \frac{1}{n} E'(B) \right] - \lambda_B = 0 , \tag{13d}$$

$$\frac{\partial \mathcal{L}}{\partial W} = -\lambda_W + \lambda_B \left[1 - \frac{\alpha_2}{\epsilon} \sum_{i=1}^{n} (1 - l_i) \right] = 0 , \tag{13e}$$

$$\mu_{l_i} \geq 0 , \quad \mu_{l_i}(1 - l_i) = 0 , \quad i = 1, \ldots, n . \tag{13f}$$

The Lagrangian $\mathcal{L}$ may not be concave, as consumption is the sum of P, H and E, where P and E are concave functions, but H is not. Hence, the necessary conditions (13) may not be sufficient for an optimal bio-economic equilibrium. The following proposition gives conditions which guarantee the strict concavity of the Lagrangian.

Proposition 1 (Strict concavity in the social optimum)
Given the maximization problem (10) subject to equations (7), (8), (9) and the inequality constraints (11), the corresponding Lagrangian $\mathcal{L}$, as given by equation (12), is strictly concave for all $\alpha_2 \in [0, \bar{\alpha}_2]$ with some $\bar{\alpha}_2 > 0$.

The proofs of all propositions are given in the appendix. Proposition 1 says that the Lagrangian $\mathcal{L}$ is strictly concave if the overall productivity of hunting is below a certain threshold, which depends on the whole set of exogenously given parameters. In the following, we assume that α_2 is such that the Lagrangian $\mathcal{L}$ is strictly concave, and thus the necessary conditions (13) are also sufficient for a unique optimal bio-economic equilibrium.

The economic interpretation of the necessary and sufficient conditions is straightforward. Condition (13a) states that in the optimum the shadow price of consumption, λ_{c_i}, equals marginal welfare for all n communities. In the optimum, the shadow price of bird, λ_B, equals the welfare gain of a marginal unit of bird, which is given by the marginal productivities of bird in hunting and the ecotourism enterprise summed up over all n communities (see condition (13d)). According to condition (13e), the shadow price of wood, λ_W, equals the shadow price of bird, λ_B, times the proportionality factor $\left[1 - \frac{\alpha_2}{\epsilon} \sum_{i=1}^{n} (1 - l_i)\right]$, which determines the relationship between wood and bird in the bioeconomic equilibrium, as given by equation (6). It captures the welfare gain (loss) due to an increase (decrease) of the bird population B induced by an increase (decrease) of the habitat size W. Conditions (13d) and (13e) also highlight the public good properties of wood W and bird B, as their levels affect the welfare of all communities simultaneously via hunting and the ecotourism enterprise.

Condition (13b) says that in the social optimum the welfare gain of an additional unit of land employed in crop production equals the shadow price of wood. Similarly, condition (13c) claims that, in the social optimum and as long as not all labor is employed in crop production (i.e. $\mu_{l_i} = 0$), the welfare gain for all n communities of employing an additional marginal unit of labor in crop production plus the welfare gain of the resulting increase in the bird population due to lower hunting pressure equals the welfare loss of reducing the amount of labor employed in hunting by a marginal unit.

Solving for the shadow prices λ_W and λ_B, and inserting into conditions (13b) and (13c) yields for all $i = 1, \ldots, n$:

$$\lambda_{c_i} P_{f_i}(f_i, l_i) = \sum_{i=1}^{n} \lambda_{c_i} \left[H_B(B, l_i) + \frac{1}{n} E'(B) \right] \left[1 - \frac{\alpha_2}{\epsilon} \sum_{j=1}^{n} (1 - l_j) \right] , \tag{14a}$$

$$\lambda_{c_i} \left[P_{l_i}(f_i, l_i) + H_{l_i}(B, l_i) \right] = -\frac{\alpha_2}{\epsilon} W \sum_{i=1}^{n} \lambda_{c_i} \left[H_B(B, l_i) + \frac{1}{n} E'(B) \right] + \mu_l \ . \tag{14b}$$

As the right hand side of equations (14) is identical for all $i = 1, \ldots, n$, so is the left hand side. This implies that the socially optimal bio-economic equilibrium is governed by identical choices of f_i and l_i of all n communities:

$$f_i = f \ , \quad l_i = l \ , \quad c_i = c \ , \quad \forall \, i = 1, \ldots, n \ . \tag{15}$$

Inserting into equations (14) yields the following two necessary and sufficient conditions for the two unknowns f and l:

$$P_f(f, l) = n \left[H_B(B, l) + \frac{1}{n} E'(B) \right] \left[1 - n \frac{\alpha_2}{\epsilon} (1 - l) \right] , \tag{16a}$$

$$P_l(f, l) + n \frac{\alpha_2}{\epsilon} W \left[H_B(B, l) + \frac{1}{n} E'(B) \right] = \hat{\mu}_l - H_l(B, l) , \tag{16b}$$

with $\hat{\mu}_l = \frac{\mu_{l_i}}{\lambda_{c_i}}$.

Due to the inequality constraints (11), the optimization problem (10) can exhibit two qualitatively different socially optimal bio-economic equilibria: a corner solution and an interior solution. In the corner solution the inequality constraints (11) hold with equality, i.e. all n communities employ their labor endowment solely in crop production.[4] In the interior solution all inequality constraints (11) are non-binding. The following proposition elaborates on these solutions.

Proposition 2 (Social optimum)
The maximization problem (10), subject to equations (7), (8), (9), and the inequality constraints (11), exhibits the following solutions:

(i) A unique corner solution $(l^\star, f^\star)$, with $l^\star = 1$ and $f^\star$ given implicitly by the solution of the equation

$$\alpha_1 \beta {f^\star}^{\beta-1} = \alpha_3 \gamma (1 - n f^\star)^{\gamma-1} \ , \tag{17}$$

if

$$\alpha_1 \geq \frac{\alpha_2 \left[1 - n f^\star - \frac{\alpha_3}{\epsilon}(1 - n f^\star)^\gamma\right]}{(1-\beta){f^\star}^\beta} \ . \tag{18}$$

(ii) Otherwise, the unique interior solution $(f^\star, l^\star)$ is given implicitly by the solution of the following system of equations:

$$\begin{aligned} 0 &= \alpha_1 \beta f^{\beta-1} l^{1-\beta} - \alpha_3 \gamma (1 - n f)^{\gamma-1} \left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^\gamma \\ &\quad - n\alpha_2 (1-l) \left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right] \ , \end{aligned} \tag{19a}$$

$$\begin{aligned} 0 &= \alpha_1 (1-\beta) f^\beta l^{-\beta} + \frac{\alpha_2}{\epsilon} \alpha_3 (1 - n f)^\gamma \left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^{\gamma-1} \\ &\quad - \alpha_2 (1 - n f) \left[1 - 2n\frac{\alpha_2}{\epsilon}(1-l)\right] \ . \end{aligned} \tag{19b}$$

For α_2 sufficiently small, an interior optimal bio-economic equilibrium depends on the exogenous parameters as given by the following table:[5]

[4] Note that there are no corner solutions with $f = 0$ and/or $l = 0$, as the marginal productivity of crop production with respect to f and l goes to infinity if f and/or l tend to zero, and there is no corner solution with $f = \frac{1}{n}$ as marginal ecotourism revenues go to infinity if f tends to $\frac{1}{n}$.

[5] A "+" ("−") indicates that the corresponding endogenous variable increases (decreases), when the corresponding exogenous parameter increases (decreases). A "?" indicates that the effect is ambiguous.

	f	l	W	B	P	H	$\frac{1}{n}E$	c
α_1	$+$	$+$	$-$	$-$	$+$	$-$	$-$	$+$
α_2	$-$	$-$	$+$	$+$	$-$	$+$	$+$	$+$
α_3	$-$	$-$	$+$	$+$	$-$	$+$	$+$	$+$
$\beta^{a)}$	$-/+$	$-/?$	$+/-$	$+/-$	$-/?$	$+/?$	$+/-$	$-/+$
$\gamma^{b)}$	$-/+$	$-/+$	$+/-$	$+/-$	$-/+$	$+/-$	$?/-$	$-$
ϵ	$-$	$-$	$+$	$+$	$-$	$?$	$+$	$+$
n	$-$	$-$	$+$	$+$	$-$	$+$	$-$	$-$

$^{a)}$ *The first (second) sign applies if* $f^\star < (>)\ l^\star$.

$^{b)}$ *The first (second) sign applies if* $f^\star < (>)\ \frac{1-e^{-\frac{1}{\gamma}}}{n}$.

Proposition 2 says that if condition (18) holds, assigning any labor to hunting is not efficient and, therefore, all labor is used in crop production. As a consequence, consumption is solely produced by farmland cultivation and ecotourism revenues. Moreover, measured in units of land necessary, wildlife is most efficiently conserved if condition (18) holds. The bird population is not diminished by hunting and the bird population develops to its maximal possible level given by the habitat size W.

From the comparative static results of the interior solution we see that the higher is the overall productivity of the ecotourism enterprise, α_3, the higher are the levels of habitat, wildlife and consumption. Thus, ecotourism has not only the potential to achieve conservation and development goals simultaneously, but it influences the optimal conservation goal. The more productive is the ecotourism enterprise, the higher are the optimal levels of wildlife and habitat. As a consequence, ecotourism is rather an activity which increases the valuation of nature conservation than just a vessel to incorporate exogenously given levels of wood and bird.

Other interesting results are that an increase in the overall productivity of hunting, α_2, increases both the optimal level of consumption derived from hunting and the optimal levels of wood and bird, and that an increase in the number of communities, n, increases the optimal levels of habitat and wildlife, while consumption per community drops. The reason for the latter result is that the negative externalities created from using land as farmland and hunting bird increase with the number of communities. However, it is crucial to keep in mind that these results only hold for sufficiently small α_2.

4 Farming, hunting and wildlife conservation in the decentralized economy

So far we have investigated the levels of wildlife and habitat conservation in the social optimum. In line with Bulte and Horan (2003), Johannesen and Skonhoft (2005), and Skonhoft and Solstad (1998), among others, we assume that the state cannot enforce the optimal levels of wood, $W^{\star}$, and bird, $B^{\star}$. Thus, the n communities face *de facto* an open access regime with respect to both wildlife and habitat. Due to the public good properties of wood and bird, the actions of individual communities impose externalities on other communities, which are not taken into account by the individual communities. Thus, in general, the decentralized solution in the unregulated open access regime falls short of the social optimum.

To see what an ICDP such as non-invasive ecotourism can achieve in terms of wildlife and habitat conservation, we investigate the decentralized outcome both in a laissez faire economy without any state interventions and in an economy where the state distributes ecotourism revenues (at least partly) among the local communities. Although sharing ecotourism revenues increases the levels of wood and bird in the decentralized solution, we will see that the negative externalities cannot be fully internalized. We, therefore, propose a more encompassing tax/subsidy regime, which allows to implement the optimal levels of wildlife and habitat. To this end, we first reflect about possible levers for policy interventions and introduce a common notation for the different decentralized regimes.

4.1 Generic decentralized solution

In principle, the social optimum can be achieved either by imposing taxes/subsidies on the inputs f and l or on the outputs P, H and E. Empirical evidence suggests that the labor distribution is private knowledge and hunting can be observed neither directly nor indirectly. As a consequence, we cannot impose a tax/subsidy on the labor distribution l and on the outcome of hunting H. We assume, however, that we can observe the level of farmland f which is cultivated and the crop output P. In addition, the state is aware of the ecotourism revenues E. Denoting the taxes/subsidies on ecotourism revenues, farmland production and the level of farmland as τ_0, τ_1 and τ_2, the consumption of community i is given by:[6]

$$c_i = (1-\tau_1)P(f_i, l_i) + H(B, l_i) - \tau_2 f_i - \frac{\tau_0}{n}E(B) \ , \qquad i = 1, \ldots, n \ , \tag{20}$$

with $\tau_0, \tau_1, \tau_2 \in \mathbb{R}$.[7] Interpreting the distribution of ecotourism revenues as a subsidy allows us to investigate different decentralized regimes by using the same notation. A laissez faire economy, for example, is given by $\tau_0 = \tau_1 = \tau_2 = 0$, while the ICDP case is given by $\tau_0 \in [-1, 0)$, $\tau_1 = \tau_2 = 0$.

In the decentralized solution, each community i chooses f_i and l_i such as to maximizes its own welfare, given the choices f_j, l_j $(j \neq i)$ of all other communities. Thus, the decentralized solution is the Nash equilibrium in which each community i solves the following maximization problem:

$$\max_{f_i, l_i} V(c_i) \ , \tag{21}$$

subject to equations (7), (8), (20), and the inequality constraints

$$0 \ \leq \ 1 - l_i \ , \tag{22a}$$

$$0 \ \leq \ 1 - \sum_{j=1}^{n} f_j \ = \ W \ . \tag{22b}$$

Note that the inequality constraint (22b) can only be binding if $\tau_0 \geq 0$. Denoting the Lagrange multipliers for the equality constraints (7), (8) and (20) by λ_B, λ_W and λ_{c_i}, and the Kuhn-Tucker parameter for the inequality constraints (22a) and (22b) by μ_{l_i} and μ_f, we derive the following Lagrangian $\mathcal{L}$:

$$\begin{aligned} \mathcal{L} \ = \ & V(c_i) + \lambda_{c_i}\left[(1-\tau_1)P(f_i, l_i) + H(B, l_i) - \tau_2 f_i - \frac{\tau_0}{n}E(B) - c_i\right] \\ & + \lambda_B \left\{\left[1 - \frac{\alpha_2}{\epsilon}\sum_{j=1}^{n}(1 - l_j)\right] W - B\right\} + \lambda_W \left(1 - \sum_{j=1}^{n} f_j - W\right) \\ & + \mu_{l_i}(1 - l_i) + \mu_f \left(1 - \sum_{j=1}^{n} f_j\right) \ . \end{aligned} \tag{23}$$

[6] We adopt the usual convention that a positive τ_i denotes a tax, while a negative τ_i resembles a subsidy.

[7] As the ecotourism enterprise is run by the state, it might be difficult to "tax" the local communities in proportion to the ecotourism revenues. However, they can certainly be "subsidized", which is, in fact, distributing the ecotourism revenues to the local communities.

The first-order conditions for an optimal solution are

$$\frac{\partial \mathcal{L}}{\partial c_i} = V'(c_i) - \lambda_{c_i} = 0 \,, \tag{24a}$$

$$\frac{\partial \mathcal{L}}{\partial f_i} = \lambda_{c_i} \left[(1-\tau_1) P_{f_i}(f_i, l_i) - \tau_2\right] - \lambda_W - \mu_f = 0 \,, \tag{24b}$$

$$\frac{\partial \mathcal{L}}{\partial l_i} = \lambda_{c_i} \left[(1-\tau_1) P_{l_i}(f_i, l_i) + H_{l_i}(B, l_i)\right] + \frac{\alpha_2}{\epsilon} W \lambda_B - \mu_{l_i} = 0 \,, \tag{24c}$$

$$\frac{\partial \mathcal{L}}{\partial B} = \lambda_{c_i} \left[H_B(B, l_i) - \frac{\tau_0}{n} E'(B)\right] - \lambda_B = 0 \,, \tag{24d}$$

$$\frac{\partial \mathcal{L}}{\partial W} = -\lambda_W + \lambda_B \left[1 - \frac{\alpha_2}{\epsilon} \sum_{i=1}^{n} (1 - l_i)\right] = 0 \,, \tag{24e}$$

$$\mu_{l_i} \geq 0 \,, \quad \mu_{l_i}(1 - l_i) = 0 \,, \tag{24f}$$

$$\mu_f \geq 0 \,, \quad \mu_f \left(1 - \sum_{j=1}^{n} f_j\right) = 0 \,. \tag{24g}$$

Comparing the necessary conditions (24) with the corresponding conditions in the social optimum (13), we see, apart from taxation, one crucial difference. The shadow price of bird, λ_B, encompasses in the decentralized solution only the own welfare gains of an additional unit of bird, and not the sum of welfare gains over all n communities. Consequently, the shadow price of wood, λ_W, only accounts for own welfare gains due to a marginal increase in the level of habitat. Here, again, the public good nature of bird B and wood W becomes obvious.

As in the case of the social optimum, the first-order conditions are not necessarily sufficient, as the Lagrangian (23) is not necessarily concave. Apart from the non-concavity of H, taxation can endanger concavity. The following proposition gives sufficient conditions for the strict concavity of the Lagrangian (23).

Proposition 3 (Strict concavity in the decentralized solution)
Given the maximization problem (21) subject to equations (7), (8), (20) and the inequality constraints (22), the corresponding Lagrangian $\mathcal{L}$ as given by equation (23) is strictly concave for all $\alpha_2 \in [0, \bar{\alpha}_2]$ with some $\bar{\alpha}_2 > 0$, if

$$\tau_0 < 0 \quad \wedge \quad \tau_1 < 1. \tag{25}$$

Again, the Lagrangian is strictly concave if α_2 is sufficiently small and there is at least some sharing of ecotourism revenues ($\tau_0 < 0$). The condition $\tau_1 < 1$ is rather a technical restriction and says that the tax on crop production has to be less than 100 %. As we will see, it is easily met in the optimal tax/subsidy regime, where $\tau_1 < 0$.

Solving equations (24d) and (24e) for the shadow prices λ_B and λ_W, and inserting into equations (24b) and (24c) yields the following reaction functions for community i:

$$(1-\tau_1)P_{f_i}(f_i,l_i) - \tau_2 = \left[H_B(B,l_i) - \frac{\tau_0}{n}E'(B)\right]\left[1 - \frac{\alpha_2}{\epsilon}\sum_{j=1}^{n}(1-l_j)\right] + \hat{\mu}_f \ , \quad (26a)$$

$$(1-\tau_1)P_{l_i}(f_i,l_i) + \frac{\alpha_2}{\epsilon}W\left[H_B(B,l_i) - \frac{\tau_0}{n}E'(B)\right] = -H_{l_i}(B,l_i) + \hat{\mu}_l \ , \quad (26b)$$

with $\hat{\mu}_f = \frac{\mu_f}{\lambda_{c_i}}$ and $\hat{\mu_{l_i}} = \frac{\mu_{l_i}}{\lambda_{c_i}}$. As all n communities are identical, we focus on symmetric Nash equilibria, i.e. $f_i = f, l_i = l, \forall\, i = 1, \ldots, n$. As a consequence, the unique symmetric Nash equilibrium $(\hat{f}, \hat{l})$ is given by the solution of the following two equations, if the conditions (25) of proposition 3 hold:

$$(1-\tau_1)P_f(f,l) - \tau_2 = \left[H_B(B,l) - \frac{\tau_0}{n}E'(B)\right]\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right] + \hat{\mu}_f \ , \quad (27a)$$

$$(1-\tau_1)P_l(f,l) + \frac{\alpha_2}{\epsilon}W\left[H_B(B,l) - \frac{\tau_0}{n}E'(B)\right] = -H_l(B,l) + \hat{\mu}_l \ . \quad (27b)$$

4.2 Laissez faire economy

As a benchmark what different tax/subsidy regimes can achieve, we first investigate a laissez faire economy, without any taxes and subsidies, i.e. $\tau_0 = \tau_1 = \tau_2 = 0$. Note that this also implies that communities do not benefit from ecotourism revenues.

With $\tau_0 = \tau_1 = \tau_2 = 0$ the first-order conditions for a symmetric Nash equilibrium reduce to:

$$P_f(f,l) = H_B(B,l)\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right] + \hat{\mu}_f \ , \quad (28a)$$

$$P_l(f,l) + \frac{\alpha_2}{\epsilon}WH_B(B,l) = -H_l(B,l) + \hat{\mu}_l \ . \quad (28b)$$

As $\tau_0 = 0$, we have to check for the additional corner solution $\hat{f} = \frac{1}{n}$. However, it is obvious that only the corner solution $\left(\hat{f} = \frac{1}{n}, \hat{l} = 1\right)$, in which conditions (22a) and (22b) hold simultaneously, can be a Nash equilibrium, as consumption from hunting vanishes in either corner solutions and consumption from crop production is the higher the higher are f and l.

Unfortunately $\tau_0 = 0$ violates condition (25) of proposition 3. As can be seen from equation (A.12) in the appendix, the Lagrangian is not concave for small α_2 and the sufficiency of the first order conditions (28) is not guaranteed. One can show that both the interior solution of the system of equations (28) (if it exists) and the corner solution

$\left(\hat{f} = \frac{1}{n}, \hat{l} = 1\right)$ are always local maxima but not necessarily global maxima. The following proposition gives details about the symmetric Nash equilibria in the laissez faire economy.

Proposition 4 (Nash equilibria in the laissez faire economy)
For $\tau_0 = \tau_1 = \tau_2 = 0$ the game, in which each community solves maximization problem (21) subject to equations (7), (8), (20), the inequality constraints (22) and given the choices of all other communities, exhibits the following symmetric Nash equilibria:

(i) The unique symmetric Nash equilibrium $\left(\frac{1}{n}, 1\right)$, if

$$\begin{aligned} \frac{\alpha_1}{n^\beta} &> \alpha_1 f^\beta l^{1-\beta} + \alpha_2(1-nf)\left[(1-l) - n\frac{\alpha_2}{\epsilon}(1-l)^2\right] \ , \\ &\forall\ (f,l) \in \left(0, \frac{1}{n}\right) \times (0,1) \ . \end{aligned} \tag{29}$$

(ii) A unique symmetric Nash equilibrium $(\hat{f}, \hat{l})$ which is given implicitly by the solution of the following system of equations

$$0 = \alpha_1 \beta f^{\beta-1} l^{1-\beta} - \alpha_2\left[(1-l) - n\frac{\alpha_2}{\epsilon}(1-l)^2\right] \ , \tag{30a}$$

$$0 = \alpha_1(1-\beta) f^\beta l^{-\beta} - \alpha_2(1-nf)\left[1 - (n+1)\frac{\alpha_2}{\epsilon}(1-l)\right] \ , \tag{30b}$$

if

$$\begin{aligned} \frac{\alpha_1}{n^\beta} &< \alpha_1 f^\beta l^{1-\beta} + \alpha_2(1-nf)\left[(1-l) - n\frac{\alpha_2}{\epsilon}(1-l)^2\right] \ , \\ &\exists\ (f,l) \in \left(0, \frac{1}{n}\right) \times (0,1) \ . \end{aligned} \tag{31}$$

(iii) Two symmetric Nash equilibria $\left(\frac{1}{n}, 1\right)$ and $(\hat{f}, \hat{l})$, the latter given implicitly by the solution of the system of equations (30), if

$$\frac{\alpha_1}{n^\beta} = \alpha_1 \hat{f}^\beta \hat{l}^{1-\beta} + \alpha_2(1-n\hat{f})\left[(1-\hat{l}) - n\frac{\alpha_2}{\epsilon}(1-\hat{l})^2\right] \ . \tag{32}$$

Apart from case (iii), which only occurs accidentally for specific parameter constellations, proposition 4 establishes that there is a unique symmetric Nash equilibrium in the laissez faire economy, which is either an interior or a corner solution. It is obvious from conditions (29) and (31) that the corner solution applies if α_2 is sufficiently small.

That is, if the overall productivity of hunting is sufficiently small, a Nash equilibrium occurs, in which all land is used as farmland. As a consequence, there is no habitat left, and the bird population becomes extinct. The reason is that, without ecotourism revenues, there is no economic incentive for habitat and wildlife conservation if hunting is very unproductive. Even if hunting is sufficiently productive to support an interior solution as a Nash equilibrium, the negative externalities of the hunting activities of individual communities on all other communities are not taken into account, and thus the levels of habitat and wildlife fall short of the social optimal levels. This may explain why the "fences and fines" approach to habitat and wildlife conservation fails if the local communities face de facto an open access regime with respect to wood and bird.[8]

4.3 Sharing ecotourism revenues

The next case we investigate is given by $\tau_1 = \tau_2 = 0$ and $\tau_0 \in [-1, 0)$. This is the ICDP case, where local communities have additional incentives to conserve habitat and wildlife as they (at least to some extent) benefit from the ecotourism revenues which hinge on the abundance of bird and wood.

As long as τ_0 is strictly negative, the inequality condition (22b) is never binding in the Nash equilibrium. Moreover, the conditions (25) of Proposition 3 are met, and thus the following two equations determine the unique symmetric Nash equilibrium if α_2 is sufficiently small:

$$P_f(f, l) = \left[H_B(B, l) - \frac{\tau_0}{n} E'(B)\right] \left[1 - n\frac{\alpha_2}{\epsilon}(1 - l)\right] \ , \tag{33a}$$

$$P_l(f, l) + \frac{\alpha_2}{\epsilon} W \left[H_B(B, l) - \frac{\tau_0}{n} E'(B)\right] = -H_l(B, l) + \hat{\mu}_l \ . \tag{33b}$$

Like in the socially optimal bioeconomic equilibrium, the Nash equilibrium can exhibit a corner solution, in which all labor is assigned to crop production, and thus no hunting is undertaken, and an interior solution, in which farmland production, hunting and the ecotourism revenues contribute to consumption. The following proposition characterizes the symmetric Nash equilibria.

Proposition 5 (Nash equilibria with sharing ecotourism revenues)
For $\tau_0 \in [-1, 0)$, $\tau_1 = \tau_2 = 0$ the game, in which each community solves maximization

[8] Note that in our model welfare solely depends on consumption. As a consequence, there are only incentives to conserve habitat and wildlife if this increases consumption either via hunting or ecotourism revenues. We do certainly not deny that there are other motivations, despite consumption, for conserving habitat and wildlife, such as traditional, ethical or religious reasons. They are, however, not captured in our model.

problem (21) subject to equations (7), (8), (20), the inequality constraints (22) and given the choices of all other communities, exhibits the following unique symmetric Nash equilibria:

(i) A unique symmetric Nash equilibrium $(\hat{f}, 1)$, where $\hat{f}$ given implicitly by the solution of the equation

$$\alpha_1 \beta f^{\beta-1} = -\frac{\tau_o}{n} \alpha_3 \gamma (1-nf)^{\gamma-1} \ , \tag{34}$$

if

$$\alpha_1 \geq \frac{\alpha_2 \left[\left(1 - n\hat{f}\right) + \frac{\tau_0 \alpha_3}{n\epsilon} \gamma \left(1 - n\hat{f}\right)^{\gamma} \right]}{(1-\beta)\hat{f}^{\beta}} \ . \tag{35}$$

(ii) Otherwise, the unique symmetric Nash equilibrium $(\hat{f}, \hat{l})$ is given implicitly by the solution of the following system of equations

$$\begin{aligned} 0 &= \alpha_1 \beta f^{\beta-1} l^{1-\beta} - \alpha_2 \left[(1-l) - n\frac{\alpha_2}{\epsilon}(1-l)^2 \right] \\ &\quad + \frac{\tau_0}{n} \alpha_3 \gamma (1-nf)^{\gamma-1} \left[1 - n\frac{\alpha_2}{\epsilon}(1-l) \right]^{\gamma} \ , \qquad (36a) \\ 0 &= \alpha_1 (1-\beta) f^{\beta} l^{-\beta} - \alpha_2 (1-nf) \left[1 - (n+1)\frac{\alpha_2}{\epsilon}(1-l) \right] \\ &\quad - \frac{\tau_0 \alpha_2}{n\epsilon} \alpha_3 \gamma (1-nf)^{\gamma} \left[1 - n\frac{\alpha_2}{\epsilon}(1-l) \right]^{\gamma-1} \ . \qquad (36b) \end{aligned}$$

For α_2 sufficiently small, an interior symmetric Nash equilibrium depends on the exogenous parameters as given by the following table:[9]

[9] A "+" ("−") indicates that the corresponding endogenous variable increases (decreases), when the corresponding exogenous parameter increases (decreases). A "?" indicates that the effect is ambiguous.

	f	l	W	B	P	H	$\frac{-\tau_0}{n}E$	c
α_1	$+$	$+$	$-$	$-$	$+$	$-$	$-$	$+$
α_2	?	?	?	?	?	?	?	$+$
α_3	$-$	$-$	$+$	$+$	$-$	$+$	$+$	$+$
$\beta^{a)}$	$-/+$	$-/?$	$+/-$	$+/-$	$-/?$	$+/?$	$+/-$	$-/+$
$\gamma^{b)}$	$-/+$	$-/+$	$+/-$	$+/-$	$-/+$	$+/-$	$+/?$	$-$
ϵ	$-$	$-$	$+$	$+$	$-$	?	$+$	$+$
$n^{c)}$	$+/-$	$+/-$	$-$	$-$	$+/-$	$-/?$	$-$	$-$
$-\tau_0$	$-$	$-$	$+$	$+$	$-$	$+$	$+$	$+$

[a] *The first (second) sign applies if* $f^\star < (>)\ l^\star$.

[b] *The first (second) sign applies if* $f^\star < (>)\ \frac{1-e^{-\frac{1}{\gamma}}}{n}$.

[c] *The first (second) sign applies if* $f^\star < (>)\ \frac{1}{(2-\gamma)n}$.

The comparative static results are similar to the social optimum. We see that the levels of habitat, wildlife and consumption are the higher, the higher is the overall productivity of ecotourism, α_3, and the higher is the share of ecotourism revenues distributed to the local communities, $-\tau_0$. The comparative static results with respect to n, however, are different from the social optimum. Under a decentralized regime with sharing ecotourism revenues, habitat and wildlife *decrease* with increasing number of communities n, while they *increase* in the social optimum. The reason is that the negative externalities of reduced wildlife and habitat levels, which are increasing in n, are not taken into account by the individual community's actions in the decentralized solution.

To see what sharing ecotourism revenues can achieve compared to the laissez faire economy and the social optimum, the following proposition ranks the different outcomes.

Proposition 6 (Comparison of outcomes under different regimes)
Denoting the labor distribution l and the levels of farmland f, wood W, the bird population B and consumption c of the social optimum, the laissez faire economy and the decentralized solution with sharing ecotourism by $(f^\star, l^\star, W^\star, B^\star, c^\star)$, $(\hat{f}^{LF}, \hat{l}^{LF}, \hat{W}^{LF}, \hat{B}^{LF}, \hat{c}^{LF})$

and $(\hat{f}^{SE}, \hat{l}^{SE}, \hat{W}^{SE}, \hat{B}^{SE}, \hat{c}^{SE})$*, the following relationships hold:*

$$f^\star < \hat{f}^{SE} < \hat{f}^{LF} , \tag{37a}$$

$$l^\star \geq \hat{l}^{SE} \geq \hat{l}^{LF} , \tag{37b}$$

$$W^\star > \hat{W}^{SE} > \hat{W}^{LF} , \tag{37c}$$

$$B^\star > \hat{B}^{SE} > \hat{B}^{LF} , \tag{37d}$$

$$c^\star > \hat{c}^{SE} > \hat{c}^{LF} , \tag{37e}$$

where the equality sign only holds in the corner solution. Moreover, the following relationship holds for the lower bound of $\bar{\alpha}_1$ *for which the corner solution with no hunting applies:*

$$\bar{\alpha}_1^\star < \bar{\alpha}_1^{SE} . \tag{38}$$

Note that there is a continuous transition from the laissez faire economy to the ICDP case. For τ_0 close to 0 the Nash equilibria of the decentralized solution with sharing ecotourism revenues are arbitrarily close to the equilibria of the laissez faire economy. Thus, in order to achieve substantial wildlife and habitat conservation, a substantial share of the ecotourism revenues has to be distributed among the communities. Moreover, from the comparative static results we know that both habitat and wildlife conservation, and consumption increase with the share, $-\tau_0$, which is distributed. Therefore, the ICDP is the more successful in achieving both goals, conserving nature and increasing the standard of living of the local population the higher is $-\tau_0$.

On the other hand, even the full distribution of ecotourism revenues among the local population, i.e. $\tau_0 = -1$, does not achieve the social optimum for $n > 1$, as the decentralized solution fails to adequately account for the negative externalities. Thus, in the decentralized ICDP case there is, in general, too much land use and too much hunting compared to the socially optimal bio-economic equilibrium and, as a consequence, lower levels of habitat, wildlife and consumption. From the relationship (38), we see that if $\alpha_1 \in (\bar{\alpha}_1^{SE}, \bar{\alpha}_1^\star)$, then hunting is individually rational under the ICDP regime, although hunting is inefficient from a socially optimal point of view. This may explain, why ICDPs often fail to achieve acceptance of strict anti-poaching regulations with the local communities.

4.4 Optimal tax/subsidy regime

From proposition 6 it is clear that sharing ecotourism revenues can indeed achieve better nature conservation and higher standard of living compared to the open access laissez faire economy. It is also clear, however, that the ICDP case fails to achieve the socially optimal bio-economic equilibrium, as the negative externalities are not adequately accounted for. In the following we introduce a more encompassing tax/subsidy mechanism, which implements the socially optimal bio-economic equilibrium as a Nash equilibrium of the decentralized economy.

Comparing the necessary conditions of the social optimum (16) and the decentralized solution (27), we seek taxes/subsidies τ_0, τ_1 and τ_2 such that:

$$0 = \tau_1 P_f(f,l) + \tau_2 - \left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]\left[(n-1)H_B(B,l) + \left(1 + \frac{\tau_0}{n}\right)E'(B)\right] \, , \tag{39a}$$

$$0 = \tau_1 P_l(f,l) + \frac{\alpha_2}{\epsilon} W \left[(n-1)H_B(B,l) + \left(1 + \frac{\tau_0}{n}\right)E'(B)\right] \; . \tag{39b}$$

If we impose, in addition, a balanced state budget

$$0 = n\tau_1 P(f,l) + n\tau_2 f + (1+\tau_0)E(B) \; , \tag{39c}$$

we get a linear system of three equations for the three unknowns τ_0, τ_1 and τ_2. This yields the unique solution:

$$\tau_0^\star = -1 - \frac{(n-1)\left[nH_B(B,l) + E'(B)\right]\left\{\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]f - \frac{\alpha_2}{\epsilon}(1-nf)l\right\}}{E(B) + E'(B)\left\{\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]f - \frac{\alpha_2}{\epsilon}(1-nf)l\right\}} \; , \tag{40a}$$

$$\tau_1^\star = -\frac{(n-1)\frac{\alpha_2}{\epsilon}(1-nf)\frac{E(B)}{P_l(f,l)}\left[H_B(B,l) + \frac{1}{n}E'(B)\right]}{E(B) + E'(B)\left\{\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]f - \frac{\alpha_2}{\epsilon}(1-nf)l\right\}} \; , \tag{40b}$$

$$\tau_2^\star = \frac{(n-1)E(B)\left[H_B(B) + \frac{1}{n}E'(B)\right]\left\{\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right] + \frac{\alpha_2\beta l}{\epsilon(1-\beta)f}(1-nf)\right\}}{E(B) + E'(B)\left\{\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]f - \frac{\alpha_2}{\epsilon}(1-nf)l\right\}} \; . \tag{40c}$$

Although there exists a unique solution for the tax/subsidy levers to achieve the same necessary conditions for the Nash equilibrium in the decentralized economy as in the social optimum, the solution might be difficult to implement if it implies taxation of the ecotourism revenues, i.e. $\tau_0^\star \geq 0$. First, if $\tau_0^\star$ is non-negative, the Lagrangian $\mathcal{L}$ (23) is not strictly concave even for small α_2. As a consequence, the social optimum might not be the only Nash equilibrium or might not even be a Nash equilibrium at all. Second, it might be difficult to politically justify a taxation of ecotourism revenues on the level of the individual communities as the revenues are earned by the state and not the individual communities. The following proposition, however, establishes that $\tau_0^\star < 0$ for α_2 sufficiently small.

Proposition 7 (Optimal tax/subsidy regime)
For $\tau_0^\star$, $\tau_1^\star$ and $\tau_2^\star$, as given by equations (40), the game in which each community solves maximization problem (21) subject to equations (7), (8), (20), the inequality constraints (22) and given the choices of all other communities, exhibits the social optimum, as given by proposition 2, as the unique Nash equilibrium for all $\alpha_2 \in [0, \bar{\alpha}_2]$ with some $\bar{\alpha}_2 > 0$. In addition, the following relationships hold:

$$\tau_0^\star < -1 \ , \qquad \tau_1^\star < 0 \ , \qquad \tau_2^\star > 0 \ . \tag{41}$$

Proposition 7 says that, if α_2 is sufficiently small, the socially optimal bio-economic equilibrium can be implemented by taxing farmland f ($\tau_2 > 0$) and subsidizing crop production P ($\tau_1 < 0$). The economic intuition is straightforward. In the laissez faire economy, communities choose too high levels of f and too small levels of l compared to the social optimum. Recall that we cannot directly tax or subsidize l as the labor distribution is private knowledge. Therefore, we have to increase the level of l indirectly by subsidizing crop production. This gives incentives to increase both the levels of labor l and land f in agricultural production. Therefore, the incentive to increase the level of farmland f has to be counteracted by taxation.

We also see from $\tau_0 < -1$ that the taxes collected from farmland outweigh the subsidies payed to crop production, while the surplus is distributed via the sharing of ecotourism revenues. This implies, however, that the tax/subsidy regime is viable even without profits from the ecotourism enterprise. Or put the other way round, the state can implement the optimal levels of wildlife and habitat and, in addition, raise funds for the provision of additional public goods such as schooling or infrastructure improvements.

5 Discussion and conclusion

Before we draw conclusions from our results and answer our initial question about why ICDPs fail, we discuss some of our model assumptions with respect to our results.

First, all our results have only been shown to be valid if the overall productivity of hunting α_2 is "sufficiently small". Formally, sufficiently small means that the Lagrangians (12) and (23) are strictly concave so that the necessary conditions (16) and (27) ensure the existence of a unique solution. In more economic terms sufficiently small means that the consumption derived from hunting is not too high compared to the consumption derived by crop production and ecotourism revenues. Although we cannot argue that this assumption is necessarily fulfilled, we consider it as the standard case. This point of view is supported by empirical evidence. Barrett and Arcese (1998) argue that, under the local conditions given in many developing countries, wildlife harvest is not profitable for most animal species. This also justifies the strict no-hunting policies of many protected areas.

Second, in our model welfare solely depends on consumption. This has two immediate consequences. On the one hand, both wood and bird are only valued with respect to their possibility to create consumption. Thus, our model does not allow for intrinsic values of wildlife and habitat due to traditional, cultural or ethical considerations. On the other hand, the choices of farmland and labor distribution are such as to maximize consumption. In particular, hunting is only undertaken to increase consumption not for traditional, ritual or religious purposes. Of course, we do not deny that there are other contributions to welfare apart from consumption and we do not deny that local communities may hunt for other reasons than game meat.[10] The reason for our model design is the desire to explain the observable overuse of habitat and wildlife in reserves with poorly enforced property rights. In our opinion the main problem is that individual economic incentives result in an overexploitation of habitat and wildlife. Intrinsic valuations of habitat and wildlife would lead to higher conservation levels both in the social optimum and in the decentralized solution, but they would still fall apart due to the public good properties of wood and bird. However, if the local communities hunt because of non-consumption motives, even a tax/subsidy regime as proposed in section 4.4 might fail to implement a strict no-hunting policy. But in this case a no-hunting policy is not socially optimal in the first place, and thus there is rather an issue of ill defined conservation goals than narrowing the gap between decentralized outcome and social optimum.

Third, for the optimal tax/subsidy regime to be implemented both land use f and crop production P have to be determined. Obviously, there are incentives for the local population to understate the land use f and to overstate crop production P in order to pay less taxes and get higher subsidies. As wood should be easily distinguished from farmland, it should be relatively easy to observe f, while it might be more difficult to determine each community's crop production. At least if local communities are not subsistence farmers, which consume substantial shares of their crop productiuon themselves,

[10] See, for example, Winkler (2006) for a bio-economic model with intrinsic values of wildlife.

the state could buy agricultural output at subsidized prizes. As local communities vary substantially, there is little general advice how to overcome these problems. It should be noted, however, that it might be at least costly to get good estimates for land use and agricultural output.

Forth, we consider a quasi-static model where we concentrate on the bio-economic equilibrium and do not take into account transition dynamics. This is justified if the population of the local communities stays constant and there are no irreversibility constraints with respect to habitat and wildlife. In fact, the local population in the vicinity of many protected areas in developing countries is growing and there are many ecosystems which exhibit irreversibility constraints.[11] Thus, we consider the extension to a dynamic model as a promising agenda for future research.

Finally, we come back to our initial question. In summary, there are four reasons why ICDPs fail. First, ICDPs may give wrong incentives, such as lump sum transfers financed by ecotourism revenues. If there is no link between the conservation and the development activity, higher transfers do not give any incentives to conserve wildlife or habitat. It is widely recognized that a successful ICDP has to communicate the link between higher levels of wildlife and habitat on the one hand, and higher income on the other hand. Second, ICDPs may give too little incentives. We have seen from proposition 6 that the outcome of the ICDP case is arbitrarily close to the laissez faire economy if τ_0 is close to 0. Thus, in order to achieve a substantial increase in nature conservation compared to the laissez faire economy, the ICDP has to promise substantial consumption gains for conservation activities. This also implies, that the development activity must be able to earn substantial and reliable revenues. Obviously, these first two reasons are well addressed in the literature and have been confirmed by our model.

Third, the ICDP may influence the conservation goal. With a profitable ecotourism enterprise established both habitat and wildlife are scarcer resources than they would be without the ecotourism business. As a consequence, the optimal conservation goal may be influenced by the development activities of the ICDP. If this is not taken into account, but the ICDP is rather thought of as an “implementation vessel” for given conservation goals, the ICDP is unlikely to achieve “optimal” conservation levels. Fourth, just establishing the link between the conservation activities and the development activities may fail to achieve the social optimum even if all revenues are distributed to the local population, because of negative externalities which arise due to public good properties of wildlife

[11] As an example think of rainforest, which does not re-grow in the same way, once slashed down to gain agricultural land.

an habitat. In our model we have two negative externalities and with the sharing of ecotourism revenues just one policy lever. In general, it is therefore not possible to achieve the socially optimal outcome. In fact, the higher is the number of communities n, the higher are the negative externalities imposed by the action of one community on all other communities, and the larger is the gap between the social optimum and the decentralized outcome in the ICDP case. This may explain why ICDPs fail to gain acceptance among the local population for strict no-hunting policies. It may be individually rational to hunt, although hunting is not socially optimal.

Nevertheless, the idea of combining conservation and development goals is appealing and can achieve substantial improvements compared to a laissez faire open access regime. In fact, we are not arguing against ICDPs but rather suggest to complement them with more encompassing tax/subsidy regimes, which take into account and correct for the negative externalities. We warn however, to underestimate the relevance of internalizing the negative externalities even if n is small. Our comparative static results show that the ICDP gives completely wrong incentives for increasing n. While an increasing n leads to higher socially optimal levels of habitat and wildlife, these levels decrease in the ICDP case. As population growth is a fact in many developing countries, the number of communities n might increase over time. Moreover, an increasing population can endanger the development goal of ICDPs. A non-growing ecological resource distributed among an increasing number of heads must eventually fail to satisfy the needs of the local population (Barrett and Arcese 1995, 1998). Although in our model the revenues created from the ICDP do not depend on wildlife harvest, the funds created by ecotourism are likely to be bounded from above. Thus, at least in the long run, the revenues created by ecotourism have to be complemented by other means to raise income. Therefore, the thorough investigation of the link between the effectiveness of ICDPs and population growth in a dynamic model is a promising avenue for future research.

Appendix

A.1 Proof of proposition 1

In the following we derive conditions which guarantee the strict concavity of the Lagrangian $\mathcal{L}$ (12). First, we neglect the inequality constraint (11). Note that if $\mathcal{L}$ is concave on $(f_i, l_i) \in \mathbb{R}^2$ than it is also concave on the restricted domain $(f_i, l_i) \in \left[0, \frac{1}{n}\right] \times [0, 1]$.

As all communities are identical, the optimization problem (10) is equivalent to maximizing the welfare of a representative community and taking into account that $f_i = f$,

$l_i = l$ and $c_i = c$ for all $i = 1, \ldots, n$. Instead of introducing the Lagrange multipliers λ_B, λ_W and λ_{c_i}, we can directly substitute the equality constraints (7), (8) and (9) into the maximization problem (10) to yield the unconstrained maximization problem:

$$\max_{\{f_i\}_{i=1}^n, \{l_i\}_{i=1}^n} V(c) \ , \tag{A.1}$$

with

$$\begin{aligned} c(f,l) &= \alpha_1 f^\beta l^{1-\beta} + \alpha_2(1-nf)\left[(1-l) - n\frac{\alpha_2}{\epsilon}(1-l)^2\right] \\ &\quad + \frac{\alpha_3}{n}(1-nf)^\gamma \left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^\gamma \ . \end{aligned} \tag{A.2}$$

As V is a strictly concave and monotonously increasing function of c, $V(c)$ is strictly quasi-concave if c is jointly strictly concave in f and l. It is easy to see that c is not concave in general. While the first and third summand are concave (and the third strictly), the second term is not. Obviously, the sum of these three terms is not necessarily strictly concave. However, c is strictly concave if the second term is small enough, i.e. the productivity of hunting, α_2, is sufficiently small.

Consumption c is strictly concave in f and l if $c_{ff} < 0$, $c_{ll} < 0$ and the determinant of the Hessian is positive, i.e. $c_{ff}c_{ll} - c_{fl}^2 > 0$. The second order derivatives of c read:

$$c_{ff} = -\alpha_1\beta(1-\beta)f^{\beta-2}l^{1-\beta} - n\alpha_3\gamma(1-\gamma)(1-nf)^{\gamma-2}\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^\gamma , \tag{A.3a}$$

$$\begin{aligned} c_{ll} &= -\alpha_1\beta(1-\beta)f^\beta l^{-\beta-1} - 2n\frac{\alpha_2^2}{\epsilon}(1-nf) \\ &\quad - n\frac{\alpha_2^2}{\epsilon^2}\alpha_3\gamma(1-\gamma)(1-nf)^\gamma\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^{\gamma-2} \ , \end{aligned} \tag{A.3b}$$

$$\begin{aligned} c_{fl} &= \alpha_1\beta(1-\beta)f^{\beta-1}l^{-\beta} + n\alpha_2\left[1 - 2n\frac{\alpha_2}{\epsilon}(1-l)\right] \\ &\quad - n\frac{\alpha_2}{\epsilon}\alpha_3\gamma^2(1-nf)^{\gamma-1}\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^{\gamma-1} \ . \end{aligned} \tag{A.3c}$$

Obviously, $c_{ff} < 0$ and $c_{ll} < 0$, but the sign of $c_{ff}c_{ll} - c_{fl}^2$ hinges upon the value of α_2. To see that $D = c_{ff}c_{ll} - c_{fl}^2 > 0$ for small α_2, we develop D in a first order Taylor series around $\alpha_2 = 0$:

$$\begin{aligned} D &\approx n\alpha_1\alpha_3\beta(1-\beta)\gamma(1-\gamma)(1-nf)^{\gamma-2}f^\beta l^{-\beta-1} - n\alpha_1\beta(1-\beta)\left\{2f^{\beta-1}l^{-\beta}\times\right. \\ &\quad \left.\times\left[1 - \frac{\alpha_3}{\epsilon}\gamma^2(1-nf)^{\gamma-1}\right] + n\frac{\alpha_3}{\epsilon}\gamma^2(1-\gamma)(1-nf)^{\gamma-2}f^\beta l^{-\beta-1}\right\}\alpha_2 \end{aligned} \tag{A.4}$$

$$= X_1 + \alpha_2 X_2 \ , \tag{A.5}$$

with $X_1 > 0$ and $X_2 < 0$. Thus, there exists a non-empty interval $I = [0, \bar{\alpha}_2)$ with $\bar{\alpha}_2 > 0$ such that $D > 0$ for all $\alpha_2 \in I$. $\square$

A.2 Proof of proposition 2

The uniqueness of the solution is guaranteed by the strict concavity of the Lagrangian $\mathcal{L}$, which is elaborated in proposition 1. The corner solution is given by $l^\star = 1$. According to equations (2), (7) and (13f) this implies $H = 0$, $B = W$ and $\hat{\mu}_l \geq 0$. Then the necessary and sufficient conditions (16) reduce to:

$$P_f(f, l) = E'(B) \ , \tag{A.6}$$

$$P_l(f, l) + \frac{\alpha_2}{\epsilon} W E'(B) \geq -H_l(B, l) \ . \tag{A.7}$$

From the first equation, we derive an implicit equation for the optimal level of farmland $f^\star$. Inserting $f^\star$ into the second equation and solving for α_1 yields the inequality (18).

The implicit equations (19) for the interior solution $(f^\star, l^\star)$ are derived from equations (16) by setting $\hat{\mu}_l = 0$ and inserting equations (7) and (8).

To derive the comparative static results we apply the implicit function theorem on equations (19). Note that equations (19) are equivalent to $c_f(f, l) = 0$ and $c_l(f, l) = 0$ with $c(f, l)$ given by equation (A.2). For presentational convenience, we introduce the following abbreviations:

$$D = \det \begin{bmatrix} c_{ff} & c_{fl} \\ c_{lf} & c_{ll} \end{bmatrix} \ , \tag{A.8a}$$

$$D_{f\square} = \det \begin{bmatrix} c_{f\square} & c_{fl} \\ c_{l\square} & c_{ll} \end{bmatrix} \ , \tag{A.8b}$$

$$D_{l\square} = \det \begin{bmatrix} c_{ff} & c_{f\square} \\ c_{fl} & c_{l\square} \end{bmatrix} \ , \tag{A.8c}$$

where $\square \in \{\alpha_1, \alpha_2, \alpha_3, \beta, \gamma, \epsilon, n\}$. Then, the comparative static results are given by (all functions evaluated at $f^\star, l^\star$):

$$\frac{df}{d\square} = -\frac{D_{f\square}}{D} \ , \qquad \frac{dl}{d\square} = -\frac{D_{l\square}}{D} \ , \tag{A.9a}$$

$$\frac{d\triangle}{d\square} = \triangle_f \frac{df}{d\square} + \triangle_l \frac{dl}{d\square} + \triangle_\square \ , \tag{A.9b}$$

$$\frac{dc}{d\square} = \underbrace{c_f}_{=0} \frac{df}{d\square} + \underbrace{c_l}_{=0} \frac{dl}{d\square} + c_\square = c_\square \ , \tag{A.9c}$$

with $\triangle \in \left\{W, B, H, P, \frac{1}{n}E\right\}$. As the sign of D depends on the value of α_2 (see proposition 1) also the signs of $\frac{df}{d\Box}$, $\frac{dl}{d\Box}$ and $\frac{d\triangle}{d\Box}$ will, in general depend on the value of α_2. As we are interested in the comparative static results for small α_2, we develop $\frac{df}{d\Box}$, $\frac{dl}{d\Box}$ and $\frac{d\triangle}{d\Box}$ into a Taylor series of the first non-vanishing order around $\alpha_2 = 0$. $\Box$

A.3 Proof of proposition 3

Analogously to the proof of proposition 1, strict concavity of the Lagrangian $\mathcal{L}$ (23) is guaranteed if consumption c_i is jointly strictly concave in f_i and l_i.

$$\begin{aligned} c(f_i, l_i) &= (1-\tau_1)\alpha_1 f_i^{\beta} l_i^{1-\beta} + \alpha_2 \left(1 - \sum_{j=1}^{n} f_j\right) \left[(1-l_i) - \frac{\alpha_2}{\epsilon}(1-l_i)\sum_{j=1}^{n}(1-l_j)\right] \\ &\quad - \tau_2 f_i - \frac{\tau_0}{n}\alpha_3 \left(1 - \sum_{j=1}^{n} f_j\right)^{\gamma} \left[1 - \frac{\alpha_2}{\epsilon}\sum_{j=1}^{n}(1-l_j)\right]^{\gamma} . \end{aligned} \tag{A.10}$$

Differentiating (A.10) twice with respect to f_i and f_i and only considering symmetric Nash equilibria, i.e. $f_j = f$, $l_j = l$, $\forall\, i = 1, \ldots n$, yields

$$\begin{aligned} c_{ff} &= -(1-\tau_1)\alpha_1\beta(1-\beta)f^{\beta-2}l^{1-\beta} \\ &\quad + \frac{\tau_0}{n}\alpha_3\gamma(1-\gamma)(1-nf)^{\gamma-2}\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^{\gamma} , \end{aligned} \tag{A.11a}$$

$$\begin{aligned} c_{ll} &= -(1-\tau_1)\alpha_1\beta(1-\beta)f^{\beta}l^{-\beta-1} - 2\frac{\alpha_2^2}{\epsilon}(1-nf) \\ &\quad + \frac{\tau_0\alpha_2^2}{n\epsilon^2}\alpha_3\gamma(1-\gamma)(1-nf)^{\gamma}\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^{\gamma-2} , \end{aligned} \tag{A.11b}$$

$$\begin{aligned} c_{fl} &= (1-\tau_1)\alpha_1\beta(1-\beta)f^{\beta-1}l^{-\beta} + \alpha_2\left[1 - (n+1)\frac{\alpha_2}{\epsilon}(1-l)\right] \\ &\quad + \frac{\tau_0\alpha_2}{n\epsilon}\alpha_3\gamma^2(1-nf)^{\gamma-1}\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right]^{\gamma-1} . \end{aligned} \tag{A.11c}$$

Developping $c_{ff}c_{ll} - c_{fl}^2$ in a first-order Taylor series around $\alpha_2 = 0$, we achieve:

$$\begin{aligned} D &\approx (1-\tau_1)\alpha_1\beta(1-\beta)\Big[-\frac{\tau_0}{n}\alpha_3\gamma(1-\gamma)(1-nf)^{\gamma-2}f^{\beta}l^{-\beta-1} - \alpha_2\Big\{2f^{\beta-1}l^{-\beta}\times \\ &\quad \times\left[1 + \frac{\tau_0\alpha_3}{n\epsilon}\gamma^2(1-nf)^{\gamma-1}\right] - \tau_0\frac{n}{\epsilon}\alpha_3\gamma^2(1-\gamma)(1-l)(1-nf)^{\gamma-2}f^{\beta}l^{-\beta-1}\Big\}\Big] \\ &= (1-\tau_1)\left[-\tau_0 X_1 - \alpha_2(-\tau_0 X_2 + X_3)\right] , \end{aligned} \tag{A.12}$$

with $X_1, X_2, X_3 > 0$. Thus, if $\tau_1 < 1$ and $\tau_0 < 0$, then $c_{ff} < 0$ and $c_{ll} < 0$, and there exists a non-empty interval $I = [0, \bar{\alpha}_2)$ with $\bar{\alpha}_2 > 0$ such that $D > 0$ for all $\alpha_2 \in I$. $\Box$

A.4 Proof of proposition 4

As the Lagrangian $\mathcal{L}$ (23) is not concave, the conditions (27) are necessary but not sufficient for a symmetric Nash equilibrium. Furthermore, uniqueness is not guaranteed.

First we show that there is at most one interior solution of equations (27). Setting $\hat{\mu}_f = \hat{\mu}_l = 0$, dividing (27a) by (27b) and re-arranging terms yields:

$$\frac{\beta(1-nf)}{(1-\beta)f} = \frac{(1-l)\left[1-n\frac{\alpha_2}{\epsilon}(1-l)\right]}{l\left[1-(n+1)\frac{\alpha_2}{\epsilon}(1-l)\right]} \ . \tag{A.13}$$

As the left-hand side is strictly monotonously decreasing for $f \in \left[0, \frac{1}{n}\right]$ and the right-hand side is strictly monotonously decreasing for $l \in \left[\max\left(0, 1-\frac{\epsilon}{(n+1)\alpha_2}\right), 1\right]$, there exists at most one interior solution. Second, from equations (A.11a) and (A.11b) we see that $c_{ff} < 0$ and $c_{ll} < 0$ for $\tau_0 = 0$. As a consequence, an interior solution (if it exists) is a local maximum.

Thus, if there is no interior solution or the interior solution yields lower welfare than the corner solution, the corner solution is the only Nash equilibrium. If there is an interior solution and it yields higher welfare than the corner solution, the interior solution is the only Nash equilibrium. If there exits an interior solution which yields the same welfare as the corner solution,we have two Nash equilibria. These three cases are tested by conditions (29), (31) and (32). □

A.5 Proof of proposition 5

The uniqueness of the solution is guaranteed by the strict concavity of the Lagrangian $\mathcal{L}$ (23), which is elaborated in proposition 3. The corner solution is given by $l^\star = 1$. According to equations (2), (7) and (13f) this implies $H = 0$, $B = W$ and $\hat{\mu}_l \geq 0$. Then the necessary and sufficient conditions (27) reduce to:

$$P_f(f,l) = -\frac{\tau_0}{n}E'(B) \ , \tag{A.14}$$

$$P_l(f,l) - \frac{\alpha_2}{\epsilon}W\frac{\tau_0}{n}E'(B) \geq -H_l(B,l) \ . \tag{A.15}$$

The first equation is an implicit equation for the optimal level of farmland $\hat{f}$. Inserting $\hat{f}$ into the second equation and solving for α_2 yields the inequality (35). The implicit equations (36) for the interior solution $(\hat{f}, \hat{l})$ are derived from equations (27) by setting $\hat{\mu}_l = 0$ and inserting equations (7) and (8).

Analogously to the proof of proposition 2, the comparative static results are derived by appling the implicit function theorem on equations (36). Given D, $D_{f\Box}$ and $D_{l\Box}$ as defined in equations (A.8) with $\Box \in \{\alpha_1, \alpha_2, \alpha_3, \beta, \gamma, \epsilon, n, -\tau_0\}$, the comparative static results are given by (all functions evaluated at $f^\star, l^\star$):

$$\frac{df}{d\Box} = -\frac{D_{f\Box}}{D}\ , \qquad \frac{dl}{d\Box} = -\frac{D_{l\Box}}{D}\ , \tag{A.16a}$$

$$\frac{d\triangle}{d\Box} = \triangle_f \frac{df}{d\Box} + \triangle_l \frac{dl}{d\Box} + \triangle_\Box\ , \tag{A.16b}$$

$$\frac{dc}{d\Box} = \underbrace{c_f}_{=0} \frac{df}{d\Box} + \underbrace{c_l}_{=0} \frac{dl}{d\Box} + c_\Box = c_\Box\ , \tag{A.16c}$$

with $\triangle \in \left\{W, B, H, P, \frac{-\tau_0}{n}E\right\}$. As the sign of D depends on the value of α_2 (see proposition 3) also the signs of $\frac{df}{d\Box}$, $\frac{dl}{d\Box}$ and $\frac{d\triangle}{d\Box}$ will, in general depend on the value of α_2. As we are interested in the comparative static results for small α_2, we develop $\frac{df}{d\Box}$, $\frac{dl}{d\Box}$ and $\frac{d\triangle}{d\Box}$ into a Taylor series of the first non-vanishing order around $\alpha_2 = 0$. $\Box$

A.6 Proof of proposition 6

Comparing the levels of f and l in the corner solution, we see from equations (17) and (34), and proposition 4 part (i):

$$f^\star < \hat{f}^{SE} < \hat{f}^{LF} = \frac{1}{n}\ , \tag{A.17a}$$

$$l^\star = \hat{l}^{SE} = \hat{l}^{LF} = 1\ . \tag{A.17b}$$

For the interior solution we compare equations (19), (30) and (36) to get:

$$P_f(l^\star, f^\star) > P_f(\hat{l}^{SE}, \hat{f}^{SE}) > P_f(\hat{l}^{LF}, \hat{f}^{LF})\ , \tag{A.18a}$$

$$P_l(l^\star, f^\star) < P_l(\hat{l}^{SE}, \hat{f}^{SE}) < P_l(\hat{l}^{LF}, \hat{f}^{LF})\ . \tag{A.18b}$$

This implies for f and l:

$$f^\star < \hat{f}^{SE} < \hat{f}^{LF}\ , \tag{A.19a}$$

$$l^\star > \hat{l}^{SE} > \hat{l}^{LF}\ . \tag{A.19b}$$

From the relationships (A.17a) and (A.19a) follow directly the relationships for the levels of wood W and bird B. The relationships for consumption c follow from the comparative static results of propositions 2 and 5.

To compare the upper bound of α_1 for which the corner solution applies between the social optimum and the ICDP case, we re-write conditions (17), (34), (18) and (35):

$$\begin{aligned} 0 &= \alpha_1 \beta f^{\beta-1} - x\alpha_3\gamma(1-nf)^{\gamma-1} \ , && \text{(A.20a)} \\ \bar{\alpha}_1 &= \frac{1-nf-x\frac{\alpha_3}{\epsilon}\gamma(1-nf)^{\gamma}}{(1-\beta)f^{\beta}} \ , && \text{(A.20b)} \end{aligned}$$

where $\bar{\alpha}_1$ denotes the lower bound of α_1 in the inequalities (18) and (35). Furthermore, $x^\star = 1$ yields conditions (17) and (18) of the social optimum, and $x^{SE} \in \left(0, \frac{1}{n}\right)$ yields conditions (34) and (35) of the ICDP case. Using the implicit function theorem we derive:

$$\begin{aligned} \frac{d\bar{\alpha}_1}{dx} &= \frac{\partial \bar{\alpha}_1}{\partial f}\frac{\partial f}{\partial x} + \frac{\partial \bar{\alpha}_1}{\partial x} && \text{(A.21a)} \\ &= -\frac{\alpha_3\gamma(1-nf)^{\gamma}}{\epsilon(1-\beta)f^{-\beta}}\left[1+\frac{x\alpha_3\gamma f(1-nf)^{\gamma}\left[\beta(1-nf)+\gamma nf\right]+\epsilon\beta(1-\beta)(1-nf)nf^2}{\alpha_1\beta(1-\beta)(1-nf)^2 f^{\beta}+xn\alpha_3\gamma(1-\gamma)(1-nf)^{\gamma}f^2}\right] \\ &< 0 \ . \end{aligned}$$

From $x^\star > x^{SE}$ follows $\bar{\alpha}_1^\star < \bar{\alpha}_1^{SE}$. □

A.7 Proof of proposition 7

Note that the conditions (41) hold if

$$\left[1 - n\frac{\alpha_2}{\epsilon}(1-l)\right] - \frac{\alpha_2}{\epsilon}(1-nf)f \geq 0 \ . \tag{A.22}$$

As both f and l are bounded from above, there exists a non-empty interval $I_1 = [0, \tilde{\alpha}_2]$ such that condition (A.22), and as a consequence, also conditions (41) hold for all $\alpha_2 \in I_1$.

In particular, $\tau_0 < 0$ and $\tau_1 < 1$ if conditions (41) hold. According to proposition 3, this implies that there is a non-empty interval $I_2 = [0, \hat{\alpha}_2]$ such that the Lagrangian $\mathcal{L}$ (23) is strictly concave for all $\alpha_2 \in I_2$, and thus the necessary conditions (27) determine the unique Nash equilibrium in the decentralized economy. Thus, setting $\bar{\alpha}_2 = \min(\tilde{\alpha}_2, \hat{\alpha}_2)$ proves the proposition. □

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