Title: Habitat Conservation: the dynamics of direct and indirect payments

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Habitat Conservation:

The Dynamics of Direct and Indirect Payments

ABSTRACT

This paper examines the dynamic efficiency of direct and indirect payments for habitat conservation, as well as the preferences of donors who make the payments. A direct (or performance) payment is an annual payment to a landowner based on the number of hectares of undisturbed habitat that the landowner has preserved. An indirect payment is an annual payment to a landowner that subsidizes the use of other, non-habitat, inputs to an "eco-friendly" activity (e.g., eco-tourism). Direct payments are dynamically efficient. They can achieve a desired level of preserved habitat at lower levels of the other, non-habitat, inputs. Direct payments, however, may not be preferred by the donor who funds the conservation effort. The analytical model is calibrated to the Ranomafana National Park in Madagascar. For the amount of funds invested in Ranomafana by international conservation organizations, direct payments generate dramatically lower costs for the conservation agent and higher profit levels for the rural residents who control the fate of the ecosystem.

Keywords: Economics; conservation; dynamic efficiency; subsidies

JEL classification: H21; Q28

I. Introduction

Between 1988 and 1996, the World Bank committed $1.25 billion in loans, credits and grants to projects with the explicit objective of conserving biodiversity. This money was estimated to have leveraged another half billion dollars (Jana and Cooke 1996: 107). In the early 1990s, the United States Agency for International Development spent $650 million annually on environmental projects (USAID 1994). Non-governmental organizations, like Conservation International and the World Wildlife Fund, have budgets of up to $100 million per year to spend on international ecosystem conservation (World Wildlife Fund 2000, Conservation International 2000). Private, philanthropic foundations also contribute millions of dollars per year to international conservation (MacArthur 2000).

Most of this money was spent on programs that sought to save habitat *indirectly* through grants and loans to developing countries to support their domestic, resource management agencies, or to impoverished individuals within those countries; individuals whose agricultural or extractive activities were thought to adversely affect natural environments or endangered species. The grants to individuals include assistance to agriculture (e.g., seed, fertilizer, and training to reduce deforestation or livestock to reduce game hunting) and to alternative technologies (e.g., capital investment and training for eco-tourism or sustainable harvest of forest products).

The effectiveness of these investments is now being questioned. For example, Kiss (2001) concludes "...we (*the conservation community*) have had little impact on stemming or even slowing the rising tide of biodiversity loss. We do not have the luxury to waste time or money on unsuccessful or highly constrained approaches. We must re-examine our paradigms and approaches to increase our effectiveness and efficiency." Other critics include Wells and

Brandon (1992), Simpson and Sedjo (1996), the World Bank (1997), Chomitz and Kumari (1998), Southgate (1998), Oates (1999), Simpson (1999), Ferraro (2001) and Rice *et al*. (2001).

Many of the critics of indirect policies and programs have noted that natural, undisturbed habitat is usually the key element in maintaining biodiversity (however defined), and that a more effective policy might be to make direct payments to a landowner, conditional on the maintenance of a parcel of land in its natural state. We refer to such a payment scheme as a *direct* payment or a "conservation performance payment." A program of direct payments assumes that property rights in land can be established and that the conservation donor would actually *prefer* the direct performance payment. In a dynamic setting, where such payments must be made over a long horizon, a donor's preference for direct payments cannot be cavalierly presumed.

This paper is concerned with the efficiency (resource cost) and donor preferences for direct versus indirect payments to conserve habitat within a dynamic allocation model. The indirect payment that we consider is a subsidy to a non-habitat input that contributes to an eco-friendly activity. For example, capital and infrastructure at an eco-tourist hotel might be combined with rainforest to produce the opportunity to see rare, tropical birds. Subsidization of capital might increase the marginal value of intact tropical forest to the owners of the hotel. Or, subsidized bee hives might increase honey production on the edge of a tropical forest and thus increase the value of intact forest to bee keepers.

Previous authors have examined the static efficiency of direct and indirect commodity taxation in the presence of externalities (Sandmo, 1976; Green and Sheshinski, 1976), the strategic aspects of output versus input subsidies in a dynamic trade policy context (Karp and Perloff, 1995), and the static efficiency of capital versus wage subsidies for employment policy

(Fuest and Huber, 2000). We are not aware of any analysis that compares the dynamic aspects of direct and indirect transfers aimed at increasing the long-run stock of a public good.

For a given level of habitat protection, we develop present-value expressions for the net revenues received by local agents and the payments made by donors and compare these expressions in transition and at one of three steady states. As might be expected, we find that direct payments are more efficient in achieving a desired level of habitat. This result was also derived in a static model by Ferraro and Simpson (2002). What is new and unique within our dynamic model is the possibility that the indirect subsidy can be preferred by a conservation donor who ultimately selects the form of transfer, an outcome that has no counterpart in the static literature on direct versus indirect transfers. Furthermore, unlike in static models in which the preferences of the donor and payment recipient are necessarily opposed, both donor and recipient can prefer the direct payment simultaneously in the dynamic model (without a side payment). A dynamic framework is also more appropriate for the empirical modeling of long-term policy interventions.

The remainder of the paper is organized as follows. In the next section we develop the dynamic model, identify the optimal approach dynamics, and derive expressions that may used to solve for any of the three relevant steady states. In Section III, we specify a Cobb-Douglas production function and calibrate the function to the Ranomafana National Park in Madagascar. In Section IV, we provide a brief discussion of transactions costs and institutional design. In the fifth and final section, we identify the conditions that we think are likely to exist when trying to preserve habitats in developing countries. Based on these conditions it seems more likely that direct performance payments will not only be the most dynamically efficient, but also the donor-preferred instrument for habitat conservation.

II. The Model

A local agent (e.g, farmer, investor, entrepreneur) stands on the edge of a rainforest frontier facing a fixed stock of forest. The local agent can clear the forest for agriculture or maintain the forest in its natural state. Clearing the forest for agriculture yields crops that can be consumed or sold. Maintaining the forest in its natural state allows the local agent to achieve private benefits through "eco-friendly" production activities, which, for the sake of clear exposition, we will assume is eco-tourism. Maintaining the forest in its natural state also produces social benefits to the global community by providing ecosystem services (e.g., hydrological regime maintenance, carbon sequestration) and shelter to endangered species, but we assume that the local agent ignores these external values when making decisions.

Let $F_t \geq 0$ denote the number of hectares of pristine rainforest in period $t=0,1,2,...,\infty$. Normalizing the size of the tract of land, we may write $F_0=1$. Let $A_t \geq 0$ denote the number of hectares in agriculture, where initially $A_0=0$. In any period $F_t + A_t = 1$, or $A_t = 1 - F_t$. Let $C_t \geq 0$ denote the hectares of land cleared of timber in period t. The dynamics of forest and agricultural land are given by the first-order difference equations $F_{t+1} - F_t = - C_t$ and $A_{t+1} - A_t = C_t$. Let I_t denote the investment in hotel facilities in period t and assume that $I_{MAX} \geq I_t \geq 0$, where I_{MAX} is an upper-bound constraint on the rate of investment. Let K_t be the accumulated stock of capital for eco-tourism (e.g., lodging). The change in the capital stock follows the first-order difference equation $K_{t+1} - K_t = - \nu K_t + I_t$, where $\nu > 0$ is the depreciation rate on capital, $K_t \geq 0$ and $K_0=0$.

Output of eco-tourism services is determined by the concave production function $Q_t = Q(K_t,F_t)$ and the unit willingness-to-pay by tourists is assumed to be given by the price $P_Q > 0$, a known constant. Let $P_K > 0$ denote the unsubsidized unit cost of investment, $P_T > 0$ the net revenue from timber harvested from a hectare of rainforest, and $P_A > 0$ the unit net revenue from produce grown on a hectare of cleared forest.

We wish to examine the dynamic effects of direct payments for forest conservation, as well as indirect payments, which take the form of a subsidy on capital investment. Let $S_F \geq 0$ denote the payment made by an International Conservation Organization (ICO) for each hectare of pristine rainforest still standing at the beginning of period t. Similarly, let $S_K \geq 0$ denote the payment by the ICO to subsidize each unit of investment (initial and depreciation) in eco-tourism capital. S_F is a *direct* subsidy for remaining rainforest, while S_K is a direct subsidy on eco-tourism capital, which the ICO hopes might *indirectly* encourage habitat (rainforest) conservation. In period t, the local agent would have a net cash flow given by

$$\pi_t = P_Q Q(K_t, F_t) - (P_K - S_K) I_t + P_T C_t + P_A(1 - F_t) + S_F F_t \qquad [1]$$

Let $\rho = 1/(1 + \delta)$ be the discount factor employed by both the local agent and the ICO, where δ is the per period rate of discount. Assume that there is also an upper-bound constraint on the rate of clear cutting so that $C_{MAX} \geq C_t \geq 0$. The maximization of net present value by the local agent may be stated mathematically as

$$\begin{aligned} &\textit{Maximize} \quad \sum_{t=0}^{\infty} \rho^t \pi_t \\ &\textit{Subject to} \quad F_{t+1} - F_t = -C_t \\ &\qquad\qquad\quad K_{t+1} - K_t = -\nu K_t + I_t \\ &\qquad\qquad\quad C_{MAX} \geq C_t \geq 0, I_{MAX} \geq I_t \geq 0 \\ &\qquad\qquad\quad F_0 = 1, K_0 = 0 \end{aligned}$$

where the control variables are C_t and I_t and the state variables are F_t and K_t. The current-value Hamiltonian for this optimization problem may be written as

$$H_t = \pi_t - \rho\lambda_{F,t+1}C_t + \rho\lambda_{K,t+1}(-vK_t + I_t) \qquad [2]$$

With the Hamiltonian linear in C_t and I_t, the optimal controls are determined by the switching functions $\sigma_{C,t} = P_T - \rho\lambda_{F,t+1}$ and $\sigma_{I,t} = -(P_K - S_K) + \rho\lambda_{K,t+1}$. If $\sigma_{C,t} > 0$, $C_t^* = C_{MAX}$, and if $\sigma_{C,t} \leq 0$, $C_t^* = 0$. Similarly, if $\sigma_{I,t} > 0$, $I_t^* = I_{MAX}$, and if $\sigma_{I,t} \leq 0$, $I_t^* = 0$. Along an optimal approach, and at the steady-state optimum, the multipliers on the forest and capital stocks must satisfy the following equations

$$\rho\lambda_{F,t+1} - \lambda_{F,t} = -\partial H_t/\partial F_t = -[P_Q Q_F(\bullet) - P_A + S_F] \qquad [3]$$

and

$$\rho\lambda_{K,t+1} - \lambda_{K,t} = -\partial H_t/\partial K_t = -[P_Q Q_K(\bullet) - v\rho\lambda_{K,t+1}] \qquad [4]$$

where $Q_F(\bullet)$ and $Q_K(\bullet)$ are the partial derivatives of $Q(K_t,F_t)$ with respect to F_t and K_t. At a steady-state optimum $\sigma_{C,t} = 0$, $\sigma_{I,t} = 0$, , $\lambda_{F,t+1} = \lambda_{F,t} = \lambda_F$ and $\lambda_{K,t+1} = \lambda_{K,t} = \lambda_K$. In steady state, the switching functions and the last two equations can be shown to imply

$$P_Q Q_F(\bullet) = \delta P_T + P_A - S_F \qquad [5]$$

$$P_Q Q_K(\bullet) = (\delta + v)(P_K - S_K) \qquad [6]$$

Equation [5] says that at a steady-state optimum the marginal value product of forest must equal the interest foregone on net timber revenue per hectare plus the net revenue forgone on an additional increment of land in agriculture less any direct subsidy paid by the ICO per hectare of standing forest. Equation [6] says that at a steady-state optimum the marginal value product of capital must equal the foregone interest on the net cost of investment, where the discount rate is adjusted (augmented) by the depreciation rate on capital.

With Q(•) concave, equations [5] and [6] will define unique, steady-state values for K and F. The values for K and F will depend on whether the ICO is offering to subsidize investment through $S_K > 0$ or intact forest through $S_F > 0$. It will be useful to identify three steady-state equilibria. The first is the "private" steady state, which the local agent would reach if S_F and S_K were both zero. Denote this private steady state as (K_P^*, F_P^*). Suppose that, from the ICO's perspective, the optimal forest stock is $F^* > F_P^*$. The ICO could induce the local agent to preserve F^* through an indirect subsidy on investment or by a direct subsidy (performance payment) for preserved forest. Denote by (K_D^*, F^*) the steady-state equilibrium where F^* is achieved with $S_F > 0$ and $S_K = 0$ and denote by (K_I^*, F^*) the steady state where F^* is achieved by $S_F = 0$ and $S_K > 0$

We can use Equations [5] and [6] to show that $K_I^* > K_D^*$. Evaluate these equations when $S_F > 0$ and $S_K = 0$ so they imply (K_D^*, F^*). Equation [6] becomes $P_Q Q_K(K_D^*, F^*) = (\delta + v)P_K$. Now evaluate them at $S_F = 0$ and $S_K > 0$ so they imply (K_I^*, F^*). Equation [6] now becomes $P_Q Q_K(K_I^*, F^*) = (\delta + v)(P_K - S_K)$. Subtracting this second version of Equation [6] from the first version and dividing both sides by P_Q implies that $Q_K(K_D^*, F^*) - Q_K(K_I^*, F^*) = (\delta + v)S_K / P_Q > 0$. With Q(•) concave the difference of the two marginal products can only be positive if $K_I^* > K_D^*$.

With $K_I^* > K_D^*$ we conclude that it is more efficient to achieve and maintain F^* through the direct performance payment, since the capital stock is smaller.[1] A lower capital stock may also desirable if, despite the "eco-friendly" label on the activity, ecosystem quality is negatively correlated with the employment of capital (e.g., more hotel rooms shelter more tourists who increase the impact on a park). Although the performance payment is efficient, will it be preferred by the ICO? To answer this question we need to consider the subsidy payments made during the approaches to (K_D^*, F^*) and (K_I^*, F^*) as well as the payments made in perpetuity once these equilibria are reached.

To keep things manageable we will assume that it is feasible and optimal to go from $F_0 = 1$ and $K_0 = 0$ to either (K_D^*, F^*) or (K_I^*, F^*) in one period.[2] This implies that $I_{MAX} \geq K_I^*$, $C_{MAX} \geq (F_0 - F^*) = (1 - F^*)$ and (K_D^*, F^*) or (K_I^*, F^*) are reached by the beginning of t=1. If the ICO were to use $S_F > 0$ and $S_K = 0$ to go to (K_D^*, F^*), the present value of its payments would be given by

$$\Gamma(S_F) = S_F F_0 + S_F F^* / \delta = S_F (1 + F^* / \delta) \qquad [7]$$

If the ICO were to use $S_K > 0$ and $S_F = 0$ to go to (K_I^*, F^*), the present value of its payments would be given by

$$\Gamma(S_K) = S_K K_I^* + S_K v K_I^* / \delta = S_K K_I^* (1 + v / \delta) \qquad [8]$$

The ICO would prefer the direct payment for forest preserved if $\Gamma(S_F) < \Gamma(S_K)$ and would prefer the indirect subsidy on investment if $\Gamma(S_F) > \Gamma(S_K)$.

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[1] One can approximate the incremental overall cost savings of using direct payments rather than indirect subsidies (i.e., difference between donor payments and additional resident profits) by $S_K \frac{(dK_I - dK_D)(v + \delta)}{2\delta} > 0$, where dK_I is the additional capital used in the steady state under a capital subsidy and dK_D is the additional capital used in the steady-state under an equivalent direct forest payment.

[2] We will relax this assumption in the empirical example.

One might think that the direct payment's ability to achieve the ICO's desired forest stock most efficiently (see above) would also ensure the lowest cost for the ICO, but our analysis shows otherwise. In the appendix, we show that a necessary and sufficient condition for the ICO to prefer the indirect subsidy (i.e., $\Gamma(S_F) > \Gamma(S_K)$) is

$$\left| S_F \left(\frac{Q_{KK}}{Q_{FK}^2 P_Q} \right) \right| < \left| \frac{-Q_{KK}}{Q_{FK}} K_P^* - (F_P^* + \delta) \right|, \qquad [9]$$

where Q_{ij} are second partial derivatives of the production function evaluated at the steady state (K_P^*, F_P^*). The smaller the relative distance between the privately optimal forest stock level of the local agent and the forest stock level desired by the ICO (implying S_F relatively small), the more likely that the ICO will find the indirect subsidy approach more cost-efficient than the direct payment approach. The intuition underlying the result is simple: when the distance between the privately optimal forest stock level chosen by the local agent and the forest stock level desired by the ICO is small, an ICO adopting a direct payment approach pays for a substantial amount of forest that is protected in the transition to the steady state, but is ultimately converted to agriculture.[3]

In the appendix, we also derive a sufficient condition for the ICO to prefer the direct payment approach (i.e., $\Gamma(S_F) < \Gamma(S_K)$):

$$\frac{-Q_{KK}}{Q_{FK}} K_P^* - F_P^* - \delta > 0 \qquad [10]$$

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[3] We are implicitly assuming that the ICO is unable to identify *ex ante* the specific units of ecosystem stock that will be protected in the steady state and thus pays for any forest protected in period *t*. Even in information-rich, high-income economies, such *ex ante* identification is difficult, and conservation agents using contracts often pay for land uses that eventually revert back to degrading patterns. For example, in the U.S. Conservation Reserve Program, the medium-term conservation contracts stipulate that payments are made as long as conservation activities are maintained during the relevant period, but there is nothing the conservation agent can do about recovering previous payments after a farmer clears the land upon contract expiration. The only option is to not renew the contract.

For any direct payment offered, the direct payment approach could never be more costly than an equivalent indirect subsidy if expression [10] is satisfied. With the exception of the discount rate, expression [10] is identical to the sufficient condition derived in the static analysis by Ferraro and Simpson (2002) that indicates when a conservation donor would prefer direct payments. They show that their condition holds as long as own-price input effects are larger than cross-price effects, which they note holds for most commonly specified production functions including homothetic production technologies. In the dynamic context, however, the discount rate drives an additional wedge between own-price effects and cross-price effects by capturing the effect of payments made on forest stock protected in transition but ultimately cut before the steady state is reached. Expression [10] is more likely to be satisfied when discount rates are low and own-price input effects are large relative to cross-price input effects.

From the perspective of the local agent, the present value of going to $(\mathrm{K}_\mathrm{D}^*, \mathrm{F}^*)$ with the encouragement of $S_F > 0$ and $S_K = 0$ is

$$\pi(S_F) = \Gamma(S_F) - P_K K_D^* + P_T(1-F^*) + [P_Q Q(K_D^*, F^*) - P_K v K_D^* + P_A(1-F^*)]/\delta \qquad [11]$$

The present value to the local agent of going to $(\mathrm{K}_\mathrm{I}^*, \mathrm{F}^*)$ with the encouragement of $S_K > 0$ and $S_F = 0$ is given by

$$\pi(S_K) = \Gamma(S_K) - P_K K_I^* + P_T(1-F^*) + [P_Q Q(K_I^*, F^*) - P_K v K_I^* + P_A(1-F^*)]/\delta \qquad [12]$$

Equations [11] and [12] assume that the local agent receives a payment at the beginning of t=0 and, after receiving this payment, clear-cuts $(1 - F^*)$, thus earning $P_T(1 - F^*)$ in net revenue from timber sales. The local agent then preserves F^* from t=1 onward.

The functions $\Gamma(S_K)$, $\Gamma(S_F)$, $\pi(S_K)$ and $\pi(S_F)$ are increasing and convex in the ICO's payment, and the indirect functions ($\Gamma(S_K), \pi(S_K)$) are increasing at a rate faster than the direct functions ($\Gamma(S_F), \pi(S_F)$).[4] The properties of $\pi(S_K)$ and $\pi(S_F)$ carry over to the incremental net-revenue functions, $d\,\pi(S_F) = \pi(K_D{}^*, F^*) - \pi(K_P{}^*, F_P{}^*)$ and $d\,\pi(S_K) = \pi(K_I{}^*, F^*) - \pi(K_P{}^*, F_P{}^*)$. Figure 1 illustrates $\Gamma(S_K)$, $\Gamma(S_F)$, $d\pi(S_K)$ and $d\pi(S_F)$. A payment-cost curve (e.g., $\Gamma(S_F)$) must be everywhere higher than its corresponding incremental net-revenue curve (e.g., $d\,\pi(S_F)$); if it were not, the local agent would have found it profitable to protect F^* without outside intervention. These properties imply two possible cases. In the first case (not pictured), $\Gamma(S_K)$ is everywhere higher than $\Gamma(S_F)$, and $d\,\pi(S_F)$ is everywhere higher than $d\,\pi(S_K)$ (i.e., expression [10] holds). Thus, for any F^*, the ICO always prefers the direct payment and the local agent always prefers the indirect subsidy. This first case is the only outcome in the static framework. In the dynamic framework, however, the payment and net-revenue curves can cross (see Figure 1). Curve-crossing can lead to one of three outcomes for a given F^*: (1) the ICO prefers the indirect approach and the local agent prefers the direct approach ($S_F \in [0, A]$), (2) both the ICO and the local agent prefer the direct approach ($S_F \in [A, B]$); and (3) the ICO prefers the direct approach and the local agent prefers the indirect approach ($S_F > B$). The dynamic efficiency of direct payments precludes the case in which both agents prefer the indirect subsidy simultaneously.

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[4] When comparing these functions, we are implicitly considering an S_K and an S_F that generate the same F^*.

III. Ranomafana National Park, Madagascar

The Ranomafana National Park, in southeastern Madagascar, covers approximately 41,5000 hectares of diverse rainforest ecosystem. In the early 1990s several non-governmental organizations funded a field conservation initiative, working with residents who live on the Park's boundary. The goal of the initiative was to increase the value of intact rainforest by providing support for three commercial, eco-production activities: forest management, apiculture (bee-keeping), and aquatic-species management (Ferraro and Razafimamonjy 1993). Our application of the preceding model will focus on the program to enhance the value of intact forest through expanding apiculture.

The underlying assumption of the apiculture initiative is simple. The production of honey and beeswax requires nectar and pollen inputs from melliferous plants, which are found in the rainforest. Larger apiculture operations at the edges of the park require larger areas of protected forest, and thus *indirectly* generate local-conservation incentives. Bee-keeping as a means to promote conservation is quite popular, and descriptions of such initiatives can be found in many conservation project documents (e.g., Ambougou 1993; PPNR 1995; Borrini-Feyerabend 1997).

The bee-keeping initiative employed a semi-modern, regionally-suited apiculture technology that used top-bar hives housed in wooden boxes. An apiculturalist allocates a fixed number of labor units per bee box and thus we take advantage of this complementarity to combine labor and bee-boxes into the variable K_t. The bee boxes are placed at the edge of the forest, F_t. The foraging pattern of bees, the finite supply of food per unit area of forest, and the prohibitive labor cost of safeguarding hives placed inside the forest, lead to decreasing returns to scale in the production of honey, Q_t. Our estimate of the production technology is based on data from Ferraro and Razafimamonjy (1993) and Ralimanana (1994): $Q_t = 54.54\,K_t^{0.36}F_t^{0.15}$, where Q is liters of honey, K is a bee box, and F is forest (1 unit = 15 hectares, which is the assumed stock controlled by a single household; thus $F_0 = 1$, as in Section II). Analytical steady-state solutions for the Cobb-Douglas specification in our dynamic model are described in the appendix.

Price data also came from Ferraro and Razafimamonjy (1993) and Ralimanana (1994). The price of honey was set at P_Q = \$1.00/liter, the price of a bee box at P_K = \$2.04, the net price of timber at P_T = \$10.00/hectare, and the net value of agricultural output per hectare at P_A = \$25.00. The discount rate of residents living on the Park's boundaries was set at $\delta = 0.20$. The depreciation rate on bee boxes was $v = 0.60$.

The current approach in Ranomafana is to subsidize the construction and acquisition of bee boxes. In the analysis below, we compare the capital subsidy approach to a conservation approach that relies on direct forest payments. We assume all prices are exogenous because the Ranomafana region is a small part of the total amount of honey, timber and crops produced in Madagascar. Based on data from household surveys conducted around the park (Ferraro 1994) and an assumed park management objective of preventing deforestation in an area of 30,000 hectares around the park's core of 11,500 hectares, we estimate that there are 2000 households immediately at the frontier of the park's boundary and each household has access to 15 hectares of forest. A 30,000-hectare ring around the core represents a penetration by rural residents of 5 kilometers from the park's boundary, which is considered the maximum likely penetration given the location of existing social and transportation infrastructure.

Numerical solutions were obtained using a finite-horizon approximation to the infinite-horizon control problem for each household. This approach is described in Conrad (1999: 27-30). In Table 1, we aggregate outcomes across all 2000 households and, for each ICO intervention, we present the steady-state forest and capital stocks, the per unit payment required to achieve a given forest conservation objective, the present value of payments by the ICO ($\Gamma(S_K)$, $\Gamma(S_F)$), the present value of additional net revenues to the Ranomafana residents ($d\pi(S_K), d\pi(S_F)$), and the present value of the overall cost savings from using the direct approach rather than the indirect approach. Without any intervention by an outside conservation agent, less than 4% of the existing stock of 30,000 hectares would remain standing in the steady state (t = 20 years and beyond).

The sufficient condition for the ICO to prefer the direct approach, [10], is not satisfied. Solving expression [9] for S_F indicates that the ICO should prefer the indirect payment approach for a small incremental increase in the steady-state forest stock, but for large incremental increases in forest stock the ICO should prefer the direct payment approach. This indeed is what we observe. For example, if the ICO desires to increase the steady-state stock of forest to 5.5% of F_0, the costs of the capital subsidy to the ICO are about 40% of the costs of the direct payment approach ($\Gamma(S_K)$ = \$328,044; $\Gamma(S_F)$ = \$795,835). The rural residents, however, prefer the direct payment approach because the increase in net revenues under the direct payment is more than twice as high as the increase under the indirect subsidy ($d\pi(S_K)$ = \$302,965; $d\pi(S_F)$ = \$794,772). Our results stand in stark contrast to those derived by Ferraro and Simpson in their static apiculture example: for a conservation objective of inducing each household to increase its forest stock by 0.10 hectares (an increase of <1% from F_p^*), they found that an ICO incurs substantially lower costs under the direct approach and the rural residents enjoy higher net revenues under the indirect approach. In a dynamic context, the policy implications are reversed.

As the ICO's conservation target increases, however, the direct payment becomes more cost-efficient for the ICO. At a conservation target of 11% of the original forest stock, the costs to the ICO are 42% lower under the direct payment approach ($\Gamma(S_K)$ = \$3,101,867; $\Gamma(S_F)$ = \$1,804,002) *and* additional net revenues to residents are 29% higher ($d\pi(S_K)$ =\$1,393,157; $d\pi(S_F)$ = \$1,791,744). Thus both agents prefer the direct approach under this conservation target. Based on our analytical results, we expect that the direct payment approach will remain preferred by the ICO for further increases in the conservation target, but eventually the profits to the rural resident will be higher under the indirect subsidy approach.

Based on documents of the Ranomafana National Park Project (PPNR 1995), we believe that the conservation target in the park is much higher than a few percentage points above the privately optimal steady-state forest stock. We derive solutions for three realistic conservation targets: 67%, 75%, and 100% of the original stock (F_0). At these conservation levels, three important observations can be made: (1) The costs to the ICO when it uses an indirect subsidy are eighty-four to one hundred and sixty-seven times the costs incurred under the direct payment; (2) The additional net revenues to the rural residents are two to three times higher when the ICO uses indirect subsidy; and (3) Without substantially relaxing the upper-bound constraint on investment (I_{max}), the ICO could not achieve *any* of the three conservation targets by using an indirect capital subsidy (we relaxed I_{max} to a value slightly above I_I^* for the indirect subsidy computations). Furthermore, the steady-state capital values under the indirect approach are unrealistically high – at much lower stocking rates, crowding among bee populations would lead to colony flight.

It is also important to note that we did not consider the ICO's budget constraint in the analysis above. In general, an ICO may have a conservation target in mind, but it is constrained by available funds. In 1991, the Ranomafana National Park Project received \$3.237 million from the U.S. Agency for International Development, \$29,000 from the Government of

Madagascar, and $654,000 from other participating organizations (USAID/Madagascar 1991). If we assume that 5% of that money would be spent on administration no matter which approach was adopted, $3.724 million remain for conservation investment. In the form of direct payments, $3.724 million would protect 80% of the original forest stock; in the form of indirect subsidies, it would protect only 12%. Direct payments in this case would also lead to a greater increase in the present value of net revenues to rural residents ($d\pi(S_K)$ = $1,253,101; $d\pi(S_F)$ = $1,791,744). Thus given the ICO's budget constraint, both the ICO and Ranomafana residents are better off under a direct payment approach (i.e., solution falls in range [A, B] in Figure 1).

IV. Transaction Costs and Institutional Design

In previous sections, we ignored a variety of issues that are important if an ICO were to implement a conservation performance payment initiative in a low-income nation. These issues include minimizing transaction costs, designing and targeting effective contracts, and developing appropriate institutional rules and roles. Despite its imposing institutional needs, a system of direct conservation payments has much in common with indirect conservation interventions. Both approaches require institutions that can monitor ecosystem health, resolve conflict, coordinate individual behavior, and allocate and enforce rights and responsibilities.

Unlike more complex indirect subsidy interventions, however, a system of conservation payments allows practitioners to focus their energies on designing the requisite institutions. In contrast, conservation practitioners using indirect approaches must allocate their resources across many more tasks in order to turn residents in remote rural areas into entrepreneurs who can cater to national and world markets. A recent World Bank report (2000) estimated that the administrative costs of running the new Costa Rican Environmental Services Payment program, which makes direct payments to rural residents for forest protection, were about 5% of the total program budget (i.e., 95% of the budget went to conservation payments). Canada's Permanent Cover Program (PCP), a conservation payment program that, in 1991, was closely integrated with its North American Waterfowl Management Plan, spent an estimated 25% of its budget on administration (OECD 1997). In contrast, Joseph Peters, former Conservation Technical Consultant with the Ranomafana National Park Project (Section III), estimated that less than 2% of the Ranomafana project's budget went to rural residents around the park; about 55% went to administrative (US-based) overhead and expatriate technical consultants and the rest went to capital expenditures and host-country technical consultants (Peters 1998). Thus, in the presence of transaction costs, the direct payment approach may be even more attractive to conservation organizations and rural residents than our analysis suggests.

V. Conclusion

In order to achieve habitat conservation objectives in low-income nations, international organizations and domestic governments have invested billions of dollars to promote "eco-friendly" commercial enterprises that *indirectly* generate local incentives for conservation. In contrast, some conservationists have been experimenting with conservation performance payments (Ferraro 2001), which create direct incentives for habitat protection. The dynamic properties of either direct or indirect conservation approaches have not been rigorously examined. In particular, the effects of these alternative approaches on the costs of conservation donors and the welfare of payment recipients have not been explored.

We find that direct payments are dynamically efficient, but unlike previous static analyses, we also find that the conservation donors who ultimately choose the form of the payment instrument may prefer to use indirect subsidies. Moreover, in static analyses of transfers between two agents, donor and recipient preferences are typically opposed in the absence of side payments; in contrast, both donors and recipients can prefer the direct payment simultaneously in the dynamic framework. Donor and recipient preferences depend crucially on the discount rate, own-price and cross-price input effects in eco-friendly production activities, and the absolute difference between the socially and privately optimal habitat stock levels.

In the context of habitat conservation in low-income nations, the conditions under which the conservation donor would find the indirect subsidy preferable to the direct payment – i.e., small absolute differences between the socially and privately optimal stock levels – are not likely to be common. Conservation biologists generally believe that most endangered habitats are threatened with severe depletion and fragmentation under prevailing incentives (Pimm et al. 2001), i.e., F_P^* is small, and conservation practitioners generally aim their interventions to protect the majority of the remaining habitat stock, i.e., S_F and F^* are large. Under such conditions, conservation donors will find direct payments substantially more cost-efficient. Moreover, given the limited budgets of conservation organizations, our empirical analysis also suggests that rural residents living near endangered habitats in low-income nations would be far better off receiving direct payments than equivalent indirect subsidies. Our analysis therefore suggests that continued experimentation with conservation performance payments in the developing world is warranted and that such payments may ultimately prove to be effective conservation investments.

Appendix

A.1. International Conservation Organization Cost Analysis

Given the assumptions of Section II, if the ICO uses a “small” direct payment, then $\Gamma(S_F) = S_F F_0 + \frac{1}{\delta} S_F F^* = S_F + \frac{1}{\delta} S_F \left(F_P{}^* + S_F \frac{\partial F}{\partial S_F} \right)$. The term $\frac{\partial F}{\partial S_F}$, evaluated at the original steady state, can be derived from totally differentiating equations [6] and [7]. Thus

$$\Gamma(S_F) = S_F + \frac{1}{\delta} S_F \left(F_P{}^* + S_F \frac{\partial F}{\partial S_F} \right) = S_F \left(1 + \frac{1}{\delta} \left(F_P{}^* + S_F \frac{-Q_{KK}}{(Q_{KK}Q_{FF} - Q_{FK}{}^2) P_Q} \right) \right) \qquad \text{[A1]}$$

where Q_{ij} are second partial derivatives of the production function evaluated at $(K_P{}^*, F_P{}^*)$.

We next solve for the indirect payment, $S^*{}_K$, that generates the same increase in the use of forest as a given (small) direct payment, $\overline{S_F}$ (i.e., after totally differentiating equations [6] and [7], set the total differential dF when $S_K = 0$ and $S_F > 0$ equal to dF when $S_K > 0$ and $S_F = 0$):

$$\overline{S_F} \frac{-Q_{KK}}{(Q_{KK}Q_{FF} - Q_{FK}{}^2)} = S^*{}_K \frac{(v+\delta) Q_{FK}}{(Q_{KK}Q_{FF} - Q_{FK}{}^2)} \qquad \text{[A2]}$$

$$\Rightarrow S_K{}^* = -\overline{S}_F \frac{Q_{KK}}{Q_{FK}} \frac{1}{(v+\delta)} \qquad \text{[A3]}$$

If the ICO uses a “small” indirect capital subsidy, its costs will be $\Gamma(S_K) = S_K K_I{}^* + \frac{1}{\delta} S_K I_I{}^* =$ $S_K K_I{}^* + \frac{1}{\delta} S_K v K_I{}^* = S_K K_I{}^* (1 + \frac{v}{\delta}) = S_K (K_P{}^* + S_K \frac{\partial K}{\partial S_K}) (1 + \frac{v}{\delta})$. The term $\frac{\partial K}{\partial S_K}$, evaluated at the original steady state, can be derived from totally differentiating equations [6] and [7]. Substituting $S_K{}^*$ from [A3] into $\Gamma(S_K)$, we obtain

$$\Gamma(S_K) = S_F \frac{-Q_{KK}}{Q_{FK}} \frac{1}{v+\delta} \left(K_P{}^* + S_F \frac{-Q_{KK}}{Q_{FK}} \frac{1}{v+\delta} \frac{Q_{FF}(v+\delta)}{(Q_{FK}{}^2 - Q_{FF}Q_{KK}) P_Q} \right) \left(\frac{\delta + v}{\delta} \right) \qquad \text{[A4]}$$

We want to know when $\Gamma(S_F) > \Gamma(S_K)$; i.e., when is

$$S_F\left(1+\frac{1}{\delta}\left(F_P{}^* + S_F\frac{-Q_{KK}}{(Q_{KK}Q_{FF}-Q_{FK}{}^2)P_Q}\right)\right) >$$

$$S_F\frac{-Q_{KK}}{Q_{FK}}\frac{1}{v+\delta}\left(K_P{}^* + S_F\frac{-Q_{KK}}{Q_{FK}}\frac{1}{v+\delta}\frac{Q_{FF}(v+\delta)}{(Q_{FK}{}^2-Q_{FF}Q_{KK})P_Q}\right)\left(\frac{\delta+v}{\delta}\right)?$$

By canceling like terms and re-arranging terms, we obtain

$$S_F\left(\frac{Q_{KK}}{Q_{FK}{}^2\,P_Q}\right) > \frac{-Q_{KK}}{Q_{FK}}K_P{}^* - F_P{}^* - \delta \qquad [A5]$$

The term $\frac{-Q_{KK}}{Q_{FK}}K_P^*$ is positive but $-(F_P^*+\delta)$ is negative, so the right-hand side of [A5] is ambiguous. The left-hand side is negative. Thus, the only way that [A5] can be satisfied is when both sides are negative and $\left|S_F\left(\frac{Q_{KK}}{Q_{FK}^2P_Q}\right)\right| < \left|\frac{-Q_{KK}}{Q_{FK}}K_P^* - (F_P^*+\delta)\right|$. Moreover, a sufficient condition for the ICO to prefer the direct payment approach is

$$\frac{-Q_{KK}}{Q_{FK}}K_P{}^* - F_P{}^* - \delta > 0 \qquad [A6]$$

A.2. Derivation Steady-State Forest Stock for Cobb-Douglas Eco-Production

When $Q_t = \alpha K_t^{\beta} F_t^{\gamma}$, the marginal products of capital and forest are $Q_K = \alpha\beta K_t^{\beta-1}F_t^{\gamma} = \beta Q/K$ and $Q_F = \alpha\gamma K_t^{\beta}F_t^{\gamma-1} = \gamma Q/F$, respectively. Equations [6] and [7] therefore imply

$F = \frac{\gamma P_Q Q}{(\delta P_T + P_A - S_F)}$ and $K = \frac{\beta P_Q Q}{(\delta + v)(P_K - S_K)}$, which further implies:

$$f \equiv \frac{F}{K} = \frac{\gamma(\delta+v)(P_K - S_K)}{\beta(\delta P_T + P_A - S_F)}. \qquad [A7]$$

Let $g \equiv \frac{(\delta P_T + P_A - S_F)}{\gamma P_Q}$. We can then express Q as a function of g and F:

$$Q = \left[\frac{(\delta P_T + P_A - S_F)}{\gamma P_Q} \right] F = gF \qquad \text{[A9]}$$

Equation [A7] implies K = F/*f*, and thus the production function implies that

$$G(F) = gF - \alpha (F/f)^{\beta} F^{\gamma} = [g - \alpha (F/f)^{\beta} F^{\gamma-1}]F = 0 .$$

Assuming that it is optimal for the local agent to retain some positive amount of forest, then $[g - \alpha (F/f)^{\beta} F^{\gamma-1}] = 0$, and this implies that the steady-state forest stock can be expressed as

$$F^{*} = \left[\frac{gf^{\beta}}{\alpha} \right]^{1/(\beta+\gamma-1)} \qquad \text{[A10]}$$

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Table 1 – Ranomafana National Park: Forest Conservation Outcomes

Conservation Outcomes Using Indirect Capital Subsidies (S_K) and Direct Forest Payments (S_F)									
Percent of F_0 Protected	*S_F (per hectare)*	*S_K (per bee box)*	*K_D^**	*K_I^**	*ICO Cost Direct* $\Gamma(S_F)$	*ICO Cost Indirect* $\Gamma(S_K)$	*Δ Net Revenue Direct* $d\pi(S_F)$	*Δ Net Revenue Indirect* $d\pi(S_K)$	*Overall Cost Savings from Using Direct*[1]
3.8%	$0.00	$0.00	45,320	45,320	$0	$0	$0	$0	$0
3.9%	$0.45	$0.06	45,520	47,680	$52,934	$18,377	$52,931	$18,120	$254
5.5%	$6.67	$0.81	49,440	108,720	$795,835	$328,044	$794,772	$302,965	$24,016
11%	$15.00	$1.56	58,080	552,560	$1,804,002	$3,101,867	$1,791,744	$1,393,157	$1,696,452
67%	$24.00	$2.00	88,760	39,600,120	$3,428,729	$286,718,270	$2,909,443	$9,934,584	$276,264,400
75%	$24.25	$2.01	91,160	51,684,640	$3,622,078	$374,426,880	$2,945,692	$11,014,123	$362,736,371
100%	$24.79	$2.02	97,520	101,936,000	$4,462,190	$745,648,878	$3,032,816	$14,330,804	$729,888,700

[1] $\Gamma(S_K) - d\,\pi(S_K) - (\Gamma(S_F) - d\,\pi(S_F)) > 0$

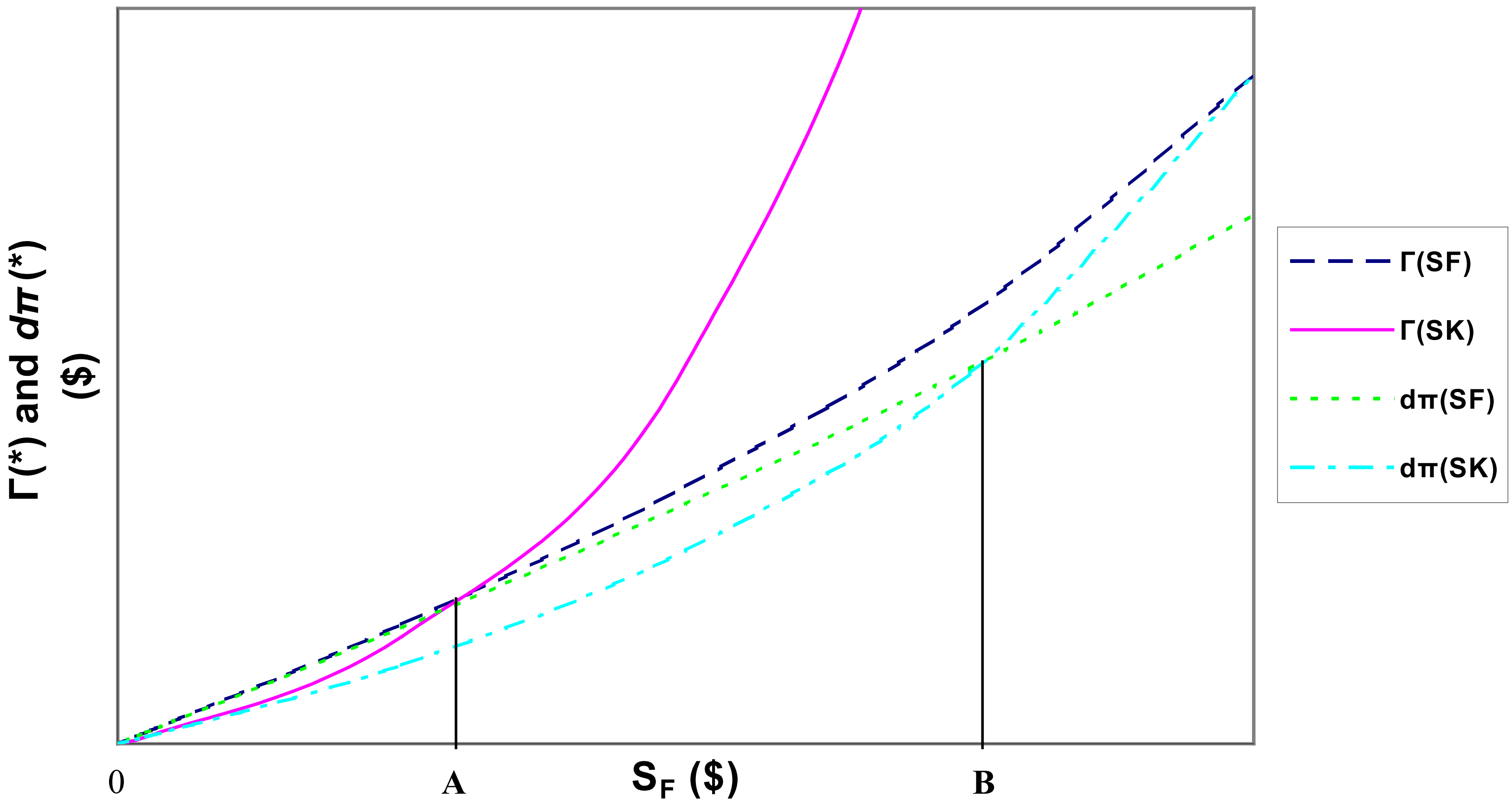

Figure 1 - Present Value of ICO Payments (Γ) and Incremental Net Revenues to Local Agent ($d\pi$) from a Direct Payment (S_F) and an Equivalent Capital Subsidy (S_K) that Protects that Same Area of Forest (F^*)