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Environmental Services and Poverty Alleviation: Either, or, or both?

By

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Environmental Services and Poverty Alleviation: Either, or, or both?

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Abstract: Payments for environmental services (PES) schemes in developing countries face trade-offs between environmental and development objectives. This tension is inherent in cost effective direct PES since, by their very nature, they limit transfers to recipients. However, where recipients of PES are subject to market constraints (e.g. credit rationing, input constraints etc.), we show that indirect payments which relax constraints can be cost effective and achieve both environmental and poverty alleviation objectives. Contrary to where markets are perfect, cost effectiveness is dependent on the nature of the recipient's production and the severity of constraints. An empirical example from Madagascar illustrates that it is unlikely these dual objectives will be achieved in the case of forest honey production, despite a severe technology constraint. Yet indirect PES schemes are shown to be cost effective where production is more closely linked to land use, such as in agriculture and forestry. This accords with recent work on agri-environmental schemes, which achieved poverty alleviation and environmental objectives by relaxing household constraints. This highlights the need to understand the market conditions, institutional context and production processes of PES recipients.

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Environmental services and poverty alleviation: Either, or, or both?*

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Abstract

Payments for environmental services (PES) schemes in developing countries face trade-offs between environmental and development objectives. This tension is inherent in cost effective 'direct' PES since, by their very nature, they limit transfers to recipients. However, where recipients of PES are subject to market constraints (e.g. credit rationing, input constraints etc.), we show that indirect payments which relax constraints can be cost effective and achieve both environmental *and* poverty alleviation objectives. Contrary to where markets are perfect, cost effectiveness is dependent on the nature of the recipient's production and the severity of constraints. An empirical example from Madagascar illustrates that it is unlikely these dual objectives will be achieved in the case of forest honey production, despite a severe technology constraint. Yet indirect PES schemes are shown to be cost effective where production is more closely linked to land use, such as in agriculture and forestry. This accords with recent work on agri-environmental schemes, which achieved poverty alleviation and environmental objectives by relaxing household constraints. This highlights the need to understand the market conditions, institutional context and production processes of PES recipients.

1 Introduction

Payments for environmental services (PES) have attracted increasing interest from both policy-makers and researchers as a mechanism to translate external, non-market values of the environment into financial incentives for local actors to provide environmental services (Engel et al., 2008). Examples include the pioneering, national-scale programme in Costa Rica (Pagiola, 2008), agri-environmental schemes in Europe (e.g. Dobbs and Pretty, 2008) and biodiversity performance payments in Sweden (Zabel and Holm-Muller, 2008). Due to evidence of negative impacts on local people from conservation programmes in the past many PES schemes in developing countries have been implemented in order not only to meet environmental policy objectives but also social or development-related objectives (Pagiola et al., 2005). Gaining the support of local, resource-dependent people via improvements to livelihoods and poverty alleviation may in turn assist in reaching conservation objectives.

Bulte et al. (2008) examine both conceptual and empirical evidence that PES in developing countries can both alleviate poverty and lead to more efficient environmental outcomes. In conclusion they suggest that the ability to reach twin goals, and hence induce 'win-win' outcomes, depends on context-specific circumstances and programme design. Tying PES and poverty alleviation may, however, result

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in lower efficiency in meeting either objective - and in fact it may be better to focus programmes on one or the other objective separately. Moreover, a failure to reach stated twin objectives may increase the likelihood of conflict between conservation donors and local people, or non-compliance (Wunder, 2005).

In this paper, we investigate the importance of market and institutional conditions faced by recipients of PES in determining the nature of cost-effective PES schemes, and when such schemes can achieve both environmental and poverty alleviation goals. Our framework for this analysis begins with a broad definition of PES. We distinguish between 'direct' and 'indirect' PES.[1] Indirect PES provide incentives to local people or recipients via some associated input to joint production of private and public goods, e.g. subsidies for capital inputs to eco-tourism, forest honey production or even to encourage agricultural set-asides. Direct PES, on the other hand, are offered directly and conditionally to recipients in exchange for land-use changes such as forest conservation.

Choice of PES intervention has been investigated under the assumption that input and output markets operate perfectly, and where market power exists (e.g. Ferraro and Simpson, 2002; 2005; Ferraro et al., 2005). These analyses highlight the obvious tension in a developing country context between the cost-effectiveness of environmental objectives on the one hand, and poverty alleviation on the other. That is, when markets are perfect and side payments are not possible, an NGO or donor always prefers cost-effective direct payments while the recipient prefers the indirect approach since she profits from the additional payments required. In short, for a given budget the cost effectiveness of one policy objective is obtained at the expense of cost effectiveness in the other.

The comparison of different approaches has been pitched as being between conditional payments for the direct delivery of some kind of environmental outcome ('direct') and an investment in , for example, an Integrated Conservation Development Project (ICDP) or Community-Based Natural Resource Management (CBNRM) scheme (see Ferraro and Kiss, 2002). While this focuses the discussion it ignores some of the more important instances in which more indirect approaches might achieve environmental and poverty alleviation objectives. For instance, empirical evidence has shown that PES interventions such as agri-environmental schemes like the Sloping Lands Conversion Programme (SLCP) in China, have achieved both environmental and poverty alleviation objectives where they were able to relax market and institutional constraints (Gauvin et al., 2009; Groom et al., 2009; Uchida et al., 2009). Elsewhere it has been shown that relaxation of constraints to the off-farm labour market can be pivotal in reducing deforestation and improving well-being in developing countries (Bluffstone 1995; Pagiola and Shively, 2004). These are important examples since market and institutional constraints such as credit rationing, input quotas, insecure tenure, and so on, are the rule rather than the exception in developing countries (e.g. Petrick 2005; Carter and Olinto 2003). In such cases, indirect payments to relax market constraints can simultaneously achieve environmental objectives and mobilise large transfers to recipients, over and above the donor's payments. Indeed, Groom and Palmer (2008) show precisely this possibility for 'indirect' PES schemes. In such cases it is not a question of either - or. Indirect PES can potentially achieve *both*.

The purpose of the paper is to better understand the context in which PES can achieve these twin objectives simultaneously. In order to illustrate the importance of market constraints in policy choice, we first apply Groom and Palmer's (2008) model of a donor seeking to influence a recipient who is subject to quantity constraints in an input market. The recipient is understood to be an 'eco-entrepreneur' of some description but could just as well be an agricultural producer. To make the analysis more concrete, we then calibrate the model to the case of constrained forest honey production in the Central Menabe region of Madagascar. As a non-timber forest product, honey production is a popular sustainable livelihood strategy applied by donors to rural households in developing countries (for a recent review, see Bradbear, 2009). This case also provides a direct comparison to the results of Ferraro and Simpson (2002) who also used forest honey production in Madagascar to illustrate their model of PES choice under perfect markets. We then analyse the efficiency, cost-effectiveness and

[1] Taken together, direct and indirect PES comprise the main policy alternatives to 'command-and-control' approaches (Ferraro and Kiss 2002).

welfare impact of direct and indirect PES on forest honey producers, where indirect payments relax an observed technological constraint and enables producers to switch from traditional to semi-modern beehives (Dirac 2009).

The analysis provides some specific and general insights on the possibility of achieving both environmental and poverty alleviation objectives. Firstly, in the case of honey production in Madagascar, we find that even where constraints are severe the donor prefers direct payments and the recipient prefers constraints to be relaxed. This preference for direct payments accords with previous findings (Ferraro and Simpson 2002; 2005; Ferraro et al., 2005) and indicates that either environmental or poverty alleviation objectives can be achieved cost-effectively, but not both in this case. Secondly, we show that despite being cost-effective, the donor's preferred direct PES is inefficient because it ignores the shadow value of relaxing the technology constraint.

More generally, whereas Ferraro and Simpson's (2002) finding is independent of the nature of technology, sensitivity analysis shows that where market constraints prevail considerations such as returns to scale and input complementarity are paramount. The case of honey production is shown to be an unlikely scenario in which the twin environment and poverty alleviation objectives will be achieved simultaneously via indirect payments. More likely scenarios might exist where production exhibiting close to constant returns to scale are employed, such as commonly found in agriculture and forestry for instance. This latter result perhaps explains the apparent success of the SLCP to achieve both environmental and poverty objectives when it effectively targeted constraints (e.g. Gauvin et al., 2009).

We show how the results depend on what is known about the constraints faced by the PES recipients and their substitution possibilities. All of which leads necessarily to a more detailed discussion of how PES should be informed by the nature of market conditions, constraints and the production process itself. Such information can assist in PES policy choice given donor objectives. For example, a focus on achieving cost-effectiveness might be critical in the design of new schemes for Reducing Emissions from Deforestation and Degradation (REDD). We also remark on the limitations of simple axiomatic models to capture the complexities of PES policy design.

The paper is organised as follows. Section 2 describes the model, while Section 3 derives the conditions for efficiency, the donor's preferences and the recipient's preferences over direct and indirect PES. Section 4 calibrates the model to the case of forest honey production in Madagascar and evaluates the performance of direct and indirect PES schemes under various possible scenarios in Madagascar. Section 5 discusses the results along with the limitations of the conceptual framework. Section 6 concludes.

2 A Model of PES with Constraints

2.1 The Model

Following Groom and Palmer (2008) we consider a PES implementing agency, an NGO or henceforth 'donor', whose sole objective is to increase forest coverage at least cost to itself, and who is unconcerned with the welfare of its recipients: it wants the 'biggest bang for the buck'.[2] On the other hand, we have a profit-maximising eco-entrepreneur, henceforth 'recipient', who operates an 'ecologically benign' production process with two variable inputs to production, forest and capital.

Forest, F, represents any ecological attribute useful in the generation of an eco-friendly output. 'Capital', K, represent some arbitrary input. Thus, a quantity, Q, of an eco-friendly product is produced using a production technology, $f(K, F)$. This technology represents an economic activity such as eco-tourism or forest honey production that allows environmental services, for instance biodiversity, to flow from the forest used in eco-production activities. The market prices of output, capital, and

[2] We ignore two important issues for simplicity: i) the objectives of the 'donor community' and NGOs need not coincide, and; ii) the distinction between households and local communities as recipients.

forest, are P_Q, P_K, and P_F, respectively, where P_F is the opportunity cost of using forest in eco-production, and may reflect the return to agriculture. It is assumed that K is a technical complement to forest in eco-production, i.e. $\frac{\partial F}{\partial P_K} < 0$.[3] We also assume that a unit of forest in eco-production provides the same quantity and quality of environmental services as a unit of conserved forest. In the absence of outside intervention, the recipient uses and thus conserves forest for eco-production. The decision of the recipient, therefore, concerns the quantity of forest to allocate to eco-production given that its cost as an input to production is P_F.

The market constraint is captured parsimoniously by assuming that capital, K, is subject to non-price rationing and limited to $\bar{K}$. As well as reflecting credit-rationing or input quotas, this constraint could also approximate missing markets $\left(\bar{K} = 0\right)$.[4] By looking at the impact of relaxing a constraint, this approach differs from the market imperfections previously addressed in relation to PES.[5]

To the cost-effectiveness of direct and indirect PES in this context we adapt the work of Fulginiti and Perrin (1993) on constrained profit functions.[6] Define the constrained profit function as:

$$\Pi^c\left(P_Q, P_F, P_K; \bar{K}, z\right) = \max_F P_Q f\left(F, K\right) - P_F F - P_K \bar{K} \tag{1}$$

This can be contrasted to the unconstrained profit function $\Pi^u\left(P_Q, P_F, P_K; z\right)$, which describes the solution to the unconstrained problem. It is straightforward to show that the constrained profit function is related to the unconstrained profit function in the following way (see Appendix A for details):

$$\Pi^C\left(P_Q, P_F, P_K; \bar{K}, z\right) = \Pi^U\left(P_Q, P_F, P_v; z\right) + \left(P_v - P_K\right)\bar{K} \tag{2}$$

where P_v is the 'virtual' or shadow price of capital, that is, the price which would induce an unrestricted recipient to choose the quantity $\bar{K}$. Each value of $\bar{K}$ has a unique virtual price. Figure 1 shows this relationship for an input constraint. Also shown in Figure 1 is the quantity $\left(P_v^0 - P_K\right)$, which is often called the 'quota rent'. This is an important determinant of the results that follow.

2.2 The PES schemes

In terms of the potential PES strategies we assume that the donor has two options for inducing greater conservation: 1) direct payments in the form of a subsidy to forest land (dP_F), or; 2) indirect provision of forest land via relaxation of the constraint on capital, $\bar{K}$ (dK). The latter could involve the provision of inputs or the relaxation of a quota on inputs or output. We compare the relative cost-effectiveness of policies in achieving a unit change on forest land assuming that no other side payments are possible.

From Hotellings Rule applied to the constrained profit function, and the derivative of the constrained profit function with respect to F yields: $-\Pi_F^C = F$. Choosing dP_F and dK so as to induce a one unit change in forested land, F, gives the following relationship[7]:

$$dF = 1 = -\Pi_{FF}^c dP_F = \frac{\partial F^C}{\partial P_F} dP_F = -\Pi_{F\bar{K}}^c dK = \frac{\partial F^C}{\partial \bar{K}} dK \tag{3}$$

The impact of the indirect policy can be expressed as (see Appendix A):

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[3] Without this assumption, a constraint on capital promotes forest cover compared to the unconstrained outcome.

[4] The model could represent an agricultural producer using land θ and on-farm labour $l^o : Q = g\left(l^o, \theta\right)$, in which forest land, F, and off-farm labour, l^w, are residuals to land and time constraints $\left(L \text{ and } \bar{\theta}\right)$: $F = \bar{\theta} - \theta$; $l^w = L - l^o$. In this context the capital constraint $\bar{K}$ could be reframed as a constraint on off-farm labour: $l^w = C$ (e.g. see Angelsen, 1999). The analysis in this context is entirely analogous: relaxing C draws labour away from agriculture and reduces land use, which increases land set aside. The direct payment could be a payment for set aside, or a tax on agricultural land. At the margin these are identical, although their distributional effects would differ.

[5] Muller and Albers (2004) model agricultural development programmes as increasing productivity of agricultural production via a multiplicative parameter $\phi : \phi f\left(F, K\right)$. As we will see, there is a correspondence between this approach and the calibration of the constraint in Section 4. Nevertheless, they ignore the value of relaxing the constraint.

[6] Parallel arguments apply to output constraints and can be easily accommodated.

[7] Note that: $\Pi_{FF}^C = \frac{\partial^2 \Pi^C}{\partial P_F^2}$ and $\Pi_{\bar{K}\bar{K}}^C = \frac{\partial^2 \Pi^C}{\partial \bar{K}^2}$.

$$1 = -\Pi^c_{F\bar{K}} dK = \frac{\Pi^u_{Fv}}{\Pi^u_{vv}} dK \tag{4}$$

where the subscript v refers to the derivative with respect to the 'virtual' price of capital, P_v. The construct of virtual prices generates a duality between constrained and unconstrained profit functions. This is convenient since it allows the constrained analysis to be undertaken using the unconstrained profit function. We now derive the conditions which determine the efficient intervention and the donor's and recipient's preferred intervention.

3 Efficiency, cost-effectiveness and donor-recipient preferences

3.1 Efficiency

Which intervention generates the greatest improvement in welfare? This is what we mean by efficiency, and it differs from the cost of conservation analysed by Ferraro and Simpson (2002; p 343). There the starting point was a perfect market equilibrium and the comparison between the direct and indirect payments compares the relative deadweight losses of each intervention. Here, the starting point is a constrained equilibrium. Figure 1 illustrates that these deadweight losses, indicated by triangles a and b, could be overwhelmed by an efficiency gain measured by the quota rent, c. Therefore, the measure of efficiency weighs the quota rent against the relative deadweight losses. Formally, Appendix B shows that where the unit resource cost of relaxing the constraint is the underlying market price P_K, direct payments for forest land are more cost-effective if the following condition holds:

$$dC = \underbrace{\frac{dK}{2}\left[-dP^I_v - dP^D_v\right]}_{\text{relative deadweight loss (b - a)}} - \underbrace{\left(P^0_v - P_K\right) dK}_{\text{released quota rent (c)}} > 0 \tag{5}$$

where dC is incremental cost of using indirect as opposed to direct payments.[8] The term dP^I_v is the change in the virtual price as a consequence of relaxing the constraint on capital, $\bar{K}$. The term dP^D_v is the change in the virtual price of capital as a consequence of the direct subsidy to forest land. Given the assumptions, the former is negative and the latter is positive. In effect, this is the dual of Ferraro and Simpson's (2002) result. The second term is the quota rent associated with relaxing the constraint, and is positive. Hence, the sign of dC is indeterminate.

Figure 1 illustrates a comparison of direct and indirect payments where the market constraint is binding. It is obvious that indirect payments are preferred to direct payments in this case since the area the area $c - b$ is larger than area a. That is, the additional profits arising from the released quota rent are sufficiently large to overcome any relative deadweight loss. The opposite result could hold if the constraint were less severe and/or the shadow price of capital low.

Ferraro and Simpson (2002) compared the deadweight loss associated with direct and indirect payments when markets function perfectly. In the context of Figure 1 they compared areas a and b and showed that the former is almost always smaller than the latter. Where markets are constrained however, the quota rent, area c, must also be considered. From the perspective of the donor, the quota rent represents a reduction in the funds required to achieve the targeted change in forest land under indirect payments, compared to direct payments where no such rents are released. From the perspective of the recipient, of course, the relaxation of constraints represents a transfer of resources. This illustrates the importance of considering the prevailing market conditions prior to determining the efficient PES intervention.

Considering market constraints introduces one further possibility: the donor may prefer an inefficient intervention simply because it ignores the quota rent. We now turn to the preferences of the donor and the recipient.

[8] Throughout the superscript 0 refers to the pre-intervention level of a variable and superscript 1 refers to the post-intervention level. Similarly, I refers to indirect intervention and D refers to direct intervention.

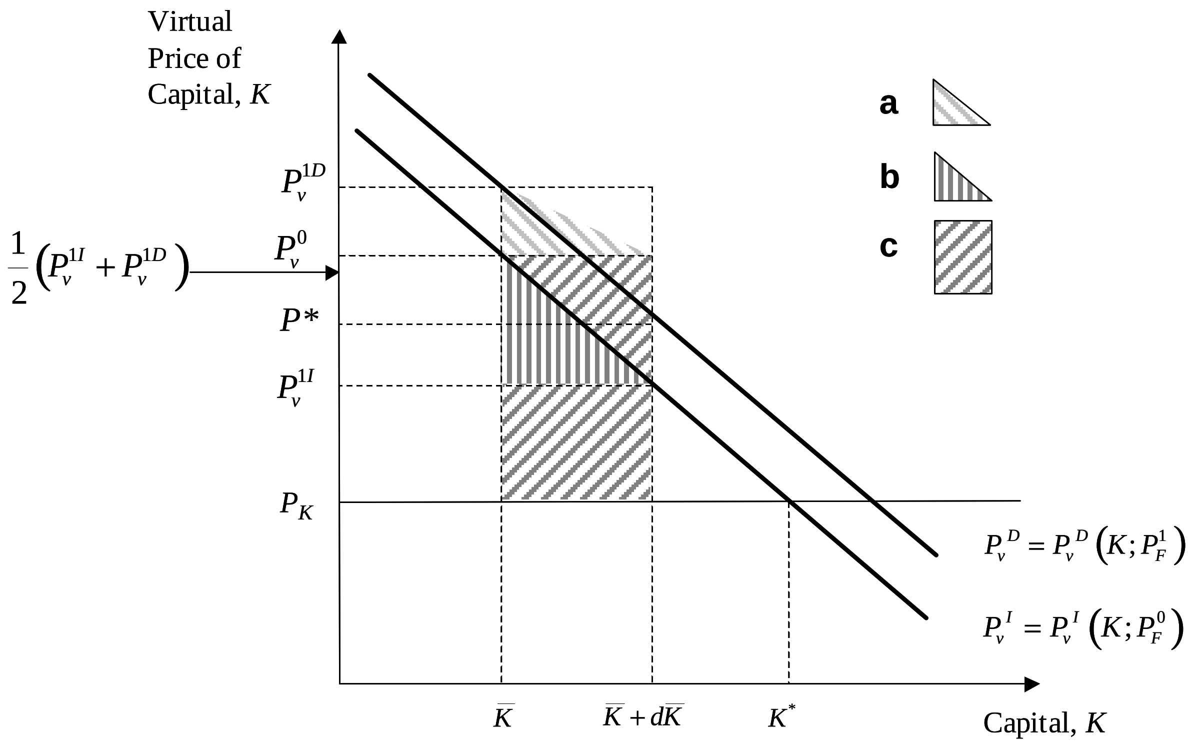

Figure 1: Direct v indirect payments for capital, K - a binding constraint

3.2 The Donor's Preferred Policy

For small changes the donor must pay either $-dP_F F$ with direct payments, or $P_K dK$ under the indirect policy of relaxing the constraints. A donor concerned solely with cost-effectiveness will prefer direct payments if:

$$-FdP_F < P_K dK \tag{6}$$

Appendix C shows that this condition becomes:

$$\frac{\eta^u_{KF}}{\eta^c_{FF}} < \eta^u_{KK} + \frac{1}{K}\frac{\partial K^u}{\partial P_v}\left(P_v^0 - P_K\right) \tag{7}$$

where η^c_{ij} is the constrained elasticity of demand for input i with respect to price of input j, and η^u_{ij} is the unconstrained equivalent.[9] The result reveals the dependence on specific features of the technology: the virtual price elasticity of demand for capital, η^U_{KK}, the quota rent associated with the constraint $\left(P_v^0 - P_K\right)$, the unconstrained cross elasticity of inputs, η^U_{KF}, and the constrained own price elasticity of demand for forest land, η^C_{FF}. In summary, condition (7) states that the donor will almost always prefer direct to indirect approaches in a world of perfect markets where quota rents are low. When binding market constraints exist, and the shadow value of the constraint is high, this conclusion is no longer robust.

[9] Elasticities are defined as follows: $\eta_{ij} = -\frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i}$.

3.3 The Recipient's Preferred Policy

When the recipient is constrained in an input market, for small changes in P_F or K, her profits will change respectively as follows:[10]

$$d\Pi_F^C = \frac{\partial \Pi^C}{\partial P_F} dP_F = -F dP_F$$

$$d\Pi_K^C = \frac{\partial \Pi^C}{\partial K} dK = P_v^0 dK$$

Hence she prefers direct payments if:

$$-F dP_F > P_v^0 dK \tag{8}$$

It is easy to see that when $P_v^0 > P_K$, conditions (6) and (8) can hold simultaneously in favour of indirect payments and both the donor and recipient will prefer this. The area of agreement is large when the quota rent is large, that is, either when the input constraint is severe or when the shadow value of the constraint is large. In this case it is possible that environmental and poverty alleviation objectives need not be in conflict since donor and recipient will agree on the appropriate PES scheme. So, particularly where constraints are severe, indirect payments may not only provide cost-effective provision of forest land from the perspective of the donor, but may also provide the largest transfer to PES recipients through released quota rent.

This gives rise to three important and related questions. Firstly, under what possible circumstances will the cost-effective PES scheme also achieve poverty alleviation goals? Secondly, will the donor prefer the efficient intervention? And thirdly, how important is it to understand market conditions before designing a PES scheme? To answer these questions we apply the framework outlined in this section to the case of forest honey production in Central Menabe, Madagascar.

4 Direct vs Indirect PES in Madagascar

4.1 Background

In this section, we illustrate the implications of constraints among potential recipients for PES policy choice in Central Menabe, located on the west coast of Madagascar. Market constraints have long been observed in Madagascar, particularly in agricultural and credit markets, which contribute to poverty among rural households (see, for example, Barratt and Dorosh, 1996; Minten and Barratt, 2008).[11] Our model is calibrated (see below) to the case of forest honey production using limited primary data on local livelihoods, collected between 2005 and 2007 (Dirac, 2009). In particular we utilise data on agricultural activities and non-timber forest products, including beekeeping.[12]

Potential PES recipients reside in poor, resource-dependent communities located at the edge of a bio-diverse rich, dry forest. Preserving biodiversity in these areas, including a number of endemic and currently endangered animal species, is one of the greatest ecological challenges that Madagascar faces (Nicoll, 2003). Deforestation via slash-and-burn agriculture occurs at an annual rate of 1 percent (Scales, 2007). A household in the study area cultivates an average of 1.86 hectares per year, typically rice, maize, cassava and peanuts. Numerous NGOs, both local and international, and donors alike

[10] The term for $d\Pi_K^C$ comes from Equation (17) in Appendix A, and assumes that the recipient receives the additional inputs for free (does not pay P_K). Of course there are distributional issues to be considered here. The division of rents does not determine the efficient outcome, but will affect preferences for one or other PES scheme. We discuss the possibility of such transfers below.

[11] In 2005, 68.7 percent of Malagasies lived below the poverty line, a figure which rose to 73.5 percent in rural areas (PNAE 2008).

[12] For example, during this time, 288 household questionnaires on local agricultural production were undertaken in six villages, while another survey comprising a further 70 questionnaires were carried out in regional markets. Further qualitative interviews were undertaken in four villages to obtain detailed information about beekeeping.

operate in the area primarily (but not necessarily exclusively) for environmental reasons.[13] Innovative policy interventions to preserve biodiversity in the region already exist on the ground. For example, the Durrell Wildlife Trust has been experimenting with an environmental auction among local communities to participate in biodiversity monitoring. Conservation payments were paid out to the 'winners' of the auction (see Durell, 2006). In our study area, NGOs have been considering various interventions including direct payments, eco-tourism and the expansion of beekeeping.

Beekeeping and honey production is well-established in Central Menabe. Bees forage in diverse natural and secondary forest formations in the vicinity of beehives. Households engaged in honey production are observed to use two types of beehive, typically located in or around villages: traditional and semi-modern.[14] On average, a representative beekeeping household owns 1.84 beehives, of which 1.2 and 0.64 are classified as traditional and semi-modern respectively. Including labour costs to build and maintain over the course of a year, traditional beehives cost US$ 8.10 per unit while semi-modern hives cost US$ 25.82. Note, however, that semi-modern hives are not constructed locally. Instead, they are donated by local NGOs. Hence, this price includes the market price paid by the NGO in addition to the costs of training local households to use the hives effectively. No market for semi-modern hives exists in the study-area villages. A traditional beehive produces an average of 15 litres of honey per year while the more productive semi-modern type produces 32 litres annually. Honey is typically sold in the villages, either to locals or middlemen who then sell honey in more distant markets. During the study period, honey prices remained stable at around US$ 2.87 per litre.

Forest honey production captures the relationships underlying the conceptual framework described in sections 2 and 3. The production of honey requires forest as an input (see Sande et al., 2009). It also requires labour and capital inputs more or less in fixed proportions. In principle, therefore, a donor wishing to conserve forests could subsidise forest land directly, or provide crucial capital inputs. Both would simultaneously enhance honey production while employing more forest land in production.

As the theory shows, where households are subject to market constraints there are countervailing arguments in favour of indirect actions to relax constraints. We now determine which intervention is cost-effective in the case of constrained honey production, and whether environmental and poverty alleviation objectives can be achieved simultaneously.

4.2 Calibration of constrained honey production

4.2.1 The technology

Ferraro and Simpson (2002) went to great lengths to characterise the semi-modern technology of honey production in Madagascar. Given our limited data, we return to their characterisation of the following Cobb-Douglas production function: $Q = AK^{\alpha}F^{\beta}$, where Q is honey production, A is a productivity parameter, α and β are the income shares of capital and forest respectively, and F and K are as before. The technology has strong diminishing returns to scale in that $\alpha = 0.36$ and $\beta = 0.15$, with $A = 48$. Due to gaps in our own data, we use these parameter values for our study of Central Menabe.

It is worth considering the information embodied in these parameters. The parameters do not explicitly reflect the fact that forest land is often non-rival in honey production. Neither do they reflect the social and other relationships between households, forests and capital, such as property rights and non-market values of land use and natural resources. In short, these parameters fail to capture many of the nuances associated with the production process. However, in addition to strongly diminishing returns to scale, α and β reflect a low output elasticity of capital, K, and particularly forest, F. This captures deterministically the low complementarity between F and K and the loose

[13] NGOs include the Durrell Wildlife Conservation Trust and Conservation International, while USAID have helped finance the establishment and management of protected areas (Ferraro and Simpson, 2002; Dirac, 2009).

[14] In traditional beekeeping, beehives are typically a single, big empty log found in the forest, closed in each side with only very small apertures for the bees. For semi-modern beekeeping, farmers use semi-modern beehives, generally Langstroth or Kenyan models. Semi-modern hives are more spacious than the traditional ones with honey produced on 'cadres' inside, which need to be periodically removed and the honey gathered. By contrast, honey is deposited inside the traditional ones, which is then collected by household members (Dirac, personal communication).

relationship between honey production and forests that might arise from non-rivalry, for instance. These parameters are important determinants in choice of PES scheme, and in our discussion we invoke this more general interpretation.

4.2.2 The constraint and behavioural assumptions

Ideally, the unconstrained and constrained demand functions can be derived in order to facilitate the analysis via an empirical analysis along the lines of Fulginiti and Perrin (1993). However, the data from Madagascar are only sufficient to calculate the descriptive statistics described above. In particular, they contain no explicit definition of the constraints faced by honey producers. Nevertheless, the presence of two types of beehive in the sample, semi-modern and traditional, allows us to identify and characterise the production constraint when combined with assumptions concerning the production technology. In particular, semi-modern beehives are significantly more productive than traditional ones, and are only used by recipients of assistance from NGOs working in the area.[15] This provides a *prima facie* case for the existence of a technological constraint underpinned by a capital constraint, which is being relaxed by external donor intervention. In order to define the constraint formally we take the following approach.

Firstly, we define the traditional technology as being a nested version of the semi-modern technology, differing only in the effective capital embodied in each beehive. That is, we can define the following general technology in terms of effective capital EK:

$$Q = A\left(EK\right)^{\alpha} F^{\beta}$$

where $E = 1$ for the traditional technology, and $E > 1$ for the semi-modern technology. K still represents the number of beehives and E represents the differences in the construction of traditional and semi-modern such as the surface area available inside the hive. EK can thus be understood as the surface area for honey production, for instance.[16] The characterisation of the technology in this way allows us to represent the traditional technology as a capital-constrained version of the semi-modern technology. As noted already a substantial outlay is required in order to obtain the new technology. In the absence of access to own funds, collateral and/or credit markets this investment will fail to materialise. The analysis of the relaxation of this constraint is one way in which to operationalise the theory presented above. This requires calibration of the value of E and $\bar{K}$.

To do this we now assume that both traditional and semi-modern producers are profit maximisers conditional on their own technology and the associated prices. This defines supply functions: $Q^T\left(P_K^T, P_F; E^T = 1\right)$ and $Q^T\left(P_K^T, P_F; E^{SM}\right)$, for each technology. These differ only because of the different values of the parameter E and the price of traditional and semi-modern beehives: P_K^T and P_K^{SM}, respectively. To define the parameter E for semi-modern producers we use the observation that the profit-maximising output of traditional production is approximately half that of unconstrained semi-modern production despite the higher price of semi-modern beehives: $Q^{SM} = 2Q^T$ (Dirac, 2009). This leads to the following definition of E^{SM}:

$$Q^{SM}\left(P_K^{SM}, P_F; E^{SM}\right) = 2Q^T\left(P_K^T, P_F; E^T = 1\right) \tag{9}$$

With E^{SM} defined, it is then possible to define the effective capital constraint, $\bar{K}$, faced by traditional producers in terms of the semi-modern technology by defining $\bar{K}$ as follows[17]:

[15] Since the semi-modern hive is more complicated to use than the traditional ones, farmers have to be trained by NGOs on how to use and manage the modern beehives. Once the farmers have learned how to manage them, the amount of work needed to operate the modern hives is approximately the same as that required for operating the traditional ones.

[16] Bradbear (2009) describes this as one major distinction between the traditional and semi-traditional technologies, alongside the need for training to use the latter, etc.

[17] Note that (9) and (10) are not identities and allow the calibration of E^{SM} at the intersection of these respective supply curves.

$$Q^{SM}\left(P_K^{SM}, P_F; E^{SM}\right) = 2Q^{SM}\left(P_K^{SM}, P_F; E^{SM}, \bar{K}\right) \tag{10}$$

The implication of (9) and (10) is that $Q^{SM}\left(P_K^{SM}, P_F; E^{SM}, \bar{K}\right) = Q^T\left(P_K^T, P_F; E^T = 1\right)$. This is the sense in which the unconstrained traditional producers are assumed to be analogous to constrained semi-modern producers.

Our method of characterising the capital constraint obviously relies heavily on the technological and behavioural assumptions. The implications are as follows. Firstly, the traditional and the constrained semi-modern have constrained supply curves (Q) and constrained demand curves for forest, $F^C(.)$, that are identical in P_F- space. However, the demand for effective capital differs between these two technologies, with the latent demand for effective capital much higher for semi-modern capital due to its higher productivity. The analysis of the relaxation of the capital constraint assumes that the honey producer is assisted in shifting from one technology to another as additional semi-modern hives are provided as part of the indirect PES scheme. The impact of indirect payments is analysed along the semi-modern demand curve rather than the traditional.[18]

This gives rise to another wrinkle for the analysis. There are two possible constrained scenarios when considering direct payments. Firstly, a *partially* constrained analysis in which direct payments induce additional traditional hives to be employed, ΔK^T. Secondly, there is a *totally* constrained scenario in which capital remains constrained at $\bar{K}$. We compare both scenarios to indirect relaxation of the constraint, $\bar{K}$, with semi-modern capital.

4.3 Direct vs indirect payments: What do stakeholders prefer?[19]

4.3.1 Defining the constraint: The constrained and unconstrained solutions

We use the following parameter values and approximations from the data for the simulation: [α, β, A, P_K^{SM}, P_K^T, P_Q, Q^{SM}/Q^T] = [0.36, 0.15, 48, 24, 8, 3, 2]. Table 1 shows the solutions to the traditional technology, the semi-modern and the constrained semi-modern that the method described above yields.

Technology	E	K	F	Q	Π
Traditional	1	18.5	0.88	134.5	201.0
Semi-Modern (Constrained)	7.7	2.4	0.88	134.5	201.0
Semi-Modern (Unconstrained)	7.7	12.3	1.76	269.0	402.0

Table 1: Characterisation of Technology Constraint

Solving for E^{SM} using (9) leads to $E^{SM} = 7.7$. The semi-modern technology, with its greater effective capital, produces greater quantities and profits while using more forest with fewer beehives. Using (10) to solve for the capital constraint yields: $\bar{K} = 2.4$. This reflects the effective capital constraint faced by households using traditional technology in terms of the semi-modern technology. This is reflected in the semi-modern constrained scenario in row three of Table 1.[20]

The simulation has two parts. Firstly, we employ the theory to estimate the subsidy to forest, dP_F, and the amount of capital, dK, required to increase forest land. We follow Ferraro and Simpson (2002) in this regard to analyse the direct or indirect payments required to effect a 0.1 hectare change in forest land for a single recipient, assuming that ten such households are subject to the intervention.

[18] This requires a correction to the profits associated with the constrained semi-modern technology in Table (1) from 291.2 to 200.1 in order to make the two coincide in all aspects. Complete details of the analysis can be obtained from the authors on request.

[19] The analytical solutions are available from the authors on request.

[20] In effect, by determining $E^M = 7.7$ we have determined that $\bar{K} = K^T/7.7 = 2.4$. We could have determined the constraint on the basis of equal profits between traditional and constrained semi-modern. Not only is this not what we observe, but this makes the constraint even more severe and hence, tips the balance even more in favour of indirect payments.

We analyse direct payments for the two possible constrained scenarios described above: partial and total. This allows us to assess the efficiency, cost-effectiveness and preferences of the donor and the recipient over these distinct PES schemes with varying market conditions.

Secondly, we undertake a comparison of these results where it is assumed that the recipient is an unconstrained producer who responds to subsidies to either forest or capital: dP_F and dP_K. That is, if market conditions are ignored.

4.3.2 What the donor prefers

Table 2 shows that in both the partially- and totally-constrained cases the donor prefers direct payments over indirect payments to release capital constraints. In the totally constrained case a direct payment of US$ 6.17 is required to induce an increase of 0.1 hectares. Since the donor must subsidise all units of forest employed, not just the marginal units, the total cost per recipient is: $-FdP_F = 6.05$. The total cost over the 10 households is US$ 60.5.[21] In the partially-constrained case households are more responsive and the cost to the donor is reduced to US$ 54.3. This shows the obvious implication that direct payments become less cost-effective the more constrained the recipients are.

Constrained Analysis (total, $\bar{K}$, and partial, ΔK^T, constraints)								
	Cost to Donor		Impact on Recipient					
Payment Scheme	1 ha	Per hshld	dK or dP_F	dQ	$d\Pi$	QR	dQR	DWL
Direct Payments $\left(\Delta K^T\right)$	54.3	5.43	5.54	3.4	5.1	NA	NA	0.31
Direct Payments $\left(\bar{K}\right)$	60.5	6.05	6.17	2.2	5.7	38.7	0	0.35
Indirect Payments	168.0	16.80	0.71	15.4	40.0	29.2	26.4	3.21
Unconstrained Analysis (following Ferraro and Simpson, 2002)								
Payment Scheme	1 ha	Per hshld	dP_F or dP_K	dQ	$d\Pi$	QR	dQR	DWL
Direct Payments	53.9	5.39	2.91	3.5	5.2	NA	NA	1.48
Indirect Payments	244.1	24.4	1.74	15.3	22.9	NA	NA	1.55

Table 2: Direct vs Indirect Payments, Constrained vs Unconstrained (US$)

Table 2 shows the outcome of indirect payments to relax constraints.[22] Although 0.7 additional units of capital (approximately 1.5 beehives) are required to induce the required increase in forest land, the cost of this to the donor across ten households is $168 where $P_K^{SM} = 24$. On the basis of the narrow objective of cost-effectiveness, it is clear that the donor would prefer direct payments. This would save in the region of US$108 per hectare of forest conserved, with a greater saving if households can introduce more traditional beehives in response. Indeed, purchasing the land outright is more cost-effective than indirect payments.

4.3.3 What the recipient prefers

Of course, that is just one side of the story. The preferences of the recipient are determined by the inequality shown in (8). Table 2 shows that the recipient clearly prefers the indirect approach to direct payments in both partially- and totally-constrained scenarios. The increase in profits from direct payments is only US$ 5.1 or US$ 5.7 with direct payments in the partially- and totally-constrained scenarios, respectively. While direct payments are increasingly desirable to the recipient when it is more constrained, the impact on profit should be compared to a change of over US$ 40 when constraints are relaxed. A significant portion of the latter is the released quota rent $\left(\left(P_v^0 - P_K^{SM}\right) dK\right)$, which is

[21] $-F.dP_F = -0.98 * -6.17 = 6.05$, where 6.17 is the payment per hectare for a household.

[22] For the constrained case column 3 measures $-FdP_F$ for direct payments and $-P_K^{SM} dK$ for the indirect relaxation of capital constraint. For the unconstrained case, column 3 shows $-FdP_F$ for direct payments, or $-KdP_K^{SM}$ for indirect payments: a price subsidy.

indicated by dQR in Table 2 and estimated to be approximately US$ 26.4. This corresponds to area c in Figure 1.[23]

In summary, when considering market conditions for the case of Malagasy honey producers, the preferences of the donor and the recipient remain in tension regardless of whether the recipient can adjust traditional capital or not. This finding accords with Ferraro and Simpson (2002) who ignored market conditions. Hence, even where honey producers are technologically constrained, environmental and poverty alleviation objectives remain in tension from the perspective of the donor: the cost-effective strategy does not induce the greatest transfer to the recipient.

4.3.4 What is efficient?

Ferraro and Simpson (2002) discuss cost-effectiveness in terms of the relative deadweight losses associated with direct and indirect payments. Where market constraints exist, however, the value of relaxing the constraint must also be considered. The presence of a market constraint means that a distinction is drawn between the broader concept of efficiency and the more narrowly-defined objectives of the donor. Under the assumption of perfect markets, what is efficient need not coincide with what the donor might consider to be cost-effective.

The efficient intervention is determined by condition (5). As predicted by Ferraro and Simpson (2002), the deadweight loss under indirect payments is larger at US$ 3.2, than for direct payments in the totally-constrained case, which are US$ 0.35 (areas b and a, respectively, in Figure (1)). However, there is a large efficiency gain as a consequence of relaxing the capital constraint, which is measured by the released quota rent of US$ 26.4, as shown in Table 2. The incremental cost of employing *direct* rather than *indirect* payments in this case is therefore US$ 23.6. This represents an important efficiency gain, much of which is the released quota rent that is transferred to the recipient. While the incremental cost declines when partial constraints are considered, the story remains the same.

In effect, the donor's contributions release extra resources which contribute both to the environmental objective and the welfare of the recipient and hence, may well have an impact on poverty. But if the donor is concerned only with the much narrower objective of cost-effectiveness, then it will prefer direct payments.

4.3.5 What if we ignore market conditions?

The lower part of Table 2 shows the outcome of the analysis if we assume that the recipients in Madagascar are unconstrained profit maximisers. The starting point for this aspect of the simulation is an unconstrained semi-modern honey producer. We then analyse the response to direct payments to forest land and indirect payments to capital in the form of subsidies, rather than relaxing capital constraints. As well as placing donor and recipient in tension, ignoring market conditions makes direct payments look more cost-effective than they really are. This can be seen in the underestimation of the costs to the donor of US$ 53.9 rather than US$ 60.5 per ha of conserved forest in the case of a totally-constrained household. On the other hand, the benefits to the recipients are underestimated: $US 5.2 instead of US$ 5.7. These and other errors arise due to the incorrect assessment of the responsiveness to prices from using unconstrained rather than constrained demand functions. This illustrates the importance of understanding the market conditions and substitution possibilities faced by recipients in assessing PES.

[23] Lastly, note that the initial quota rent $\left(P_v^0 - P_K^{SM}\right)$ is US$ 37.7. Under direct payments this increases to US$ 38.7 as the virtual price increases. Under indirect payments the constraint is relaxed and the quota rent declines to US$ 29.2.

5 Environment and poverty alleviation: Either, or, or both?

5.1 Sensitivity analysis

In the case of Madagascar, the technological and other considerations are such that the donor will prefer direct payments for forest conservation, even when market conditions are considered. The recipient, on the other hand, will prefer indirect relaxation of capital constraints. This finding accords with Ferraro and Simpson (2002). However, the results differ in that the efficient course of action is to employ indirect payments in honey production. In the case of honey production, it seems that there will always be a tension here between the role that PES can play in obtaining environmental objectives and its role in improving well-being and reducing poverty.

Nevertheless, the theory illustrates the possibility that dual objectives need not be in tension at all (see (8) and (6)). The results are clearly going to be sensitive to the assumptions concerning the technological parameters, as well as the relative prices of inputs and outputs. In this section we undertake a sensitivity analysis of the simulation in order to identify the conditions under which the preferences of the donor and recipient may or may not be in tension. This enables us to identify when environmental and poverty alleviation objectives may be achieved simultaneously. This leads to a discussion of the extent to which the axiomatic approach taken here is useful in analysing PES design before discussing some broader issues associated with the choice of policy.

Since it is obvious how variation in the price variables will affect the result, the interesting parameters are those describing the technology. In the Cobb-Douglas case, the conditions for donor and recipient to prefer indirect payments (conditions (6) and (8) respectively) become:[24]

$$\beta < \frac{P_K}{P_v^0}, \text{ and } 1 < \frac{1}{\beta} \tag{11}$$

This indicates that the recipient will prefer indirect payments for any value of β which is less than one. Yet as argued by Ferraro and Simpson (2002), this is highly likely in the case of honey production. It is also very likely in general, so we take it as given that the recipient always prefers indirect payments. Taking $\bar{K}$ as given, the quantity $\beta - P_K/P_v^0$ is plotted in Figure 2 for varying values of α and β.[25] In order to compare these combinations to a constant-returns-to-scale technology, combinations of α and β such that $\alpha + \beta = 1$ are also plotted.

Figure 2 shows that for a given constraint and for a given value of α, higher values of β will tend to induce the donor to prefer indirect payments. Similarly, for a given value of β, larger values of α will induce preferences for indirect payments. Thus, the complementarity of inputs is an important determinant of PES preferences. In particular, note that the elasticity of F with respect to K along the constrained demand curve is given by $\frac{\alpha}{1-\beta}$, which is increasing in α and β. The higher the responsiveness of forest to changes in the capital constraint, the more likely it is that indirect payments will be preferred by the donor.

Returns to scale are also important in determining the donor's preferred PES scheme. For extreme values of one or other parameter, the donor will prefer indirect payments only for technologies which are close to constant returns to scale. For intermediate values of each parameter, i.e. where both are close to 0.5, a range of decreasing-returns-to-scale technologies can support indirect payments to relax constraints. The case in hand, honey production, is also indicated in Figure 2. Here the production elasticity of forest, β, is extremely small, returns to scale are strongly decreasing and direct payments are clearly preferred. Of course, this conclusion is dependent on the price of relaxing the constraint, P_K. Figure 3 in Appendix D shows that if $P_K = 1$ then indirect payments to relax constraints would be preferred.

[24] This is true in the Cobb-Douglas case, since $\alpha = P_v\bar{K}/P_QQ$ and $\beta = P_FF/P_QQ$.

[25] P_v is given by $P_v = P_Q\alpha AE^\alpha\bar{K}^{\alpha-1}F^\beta$. Hence, from (11) the quantity $\beta - P_K\left(P_Q\alpha AE^\alpha\bar{K}^{\alpha-1}F^\beta\right)^{-1}$ is plotted in Figure 2.

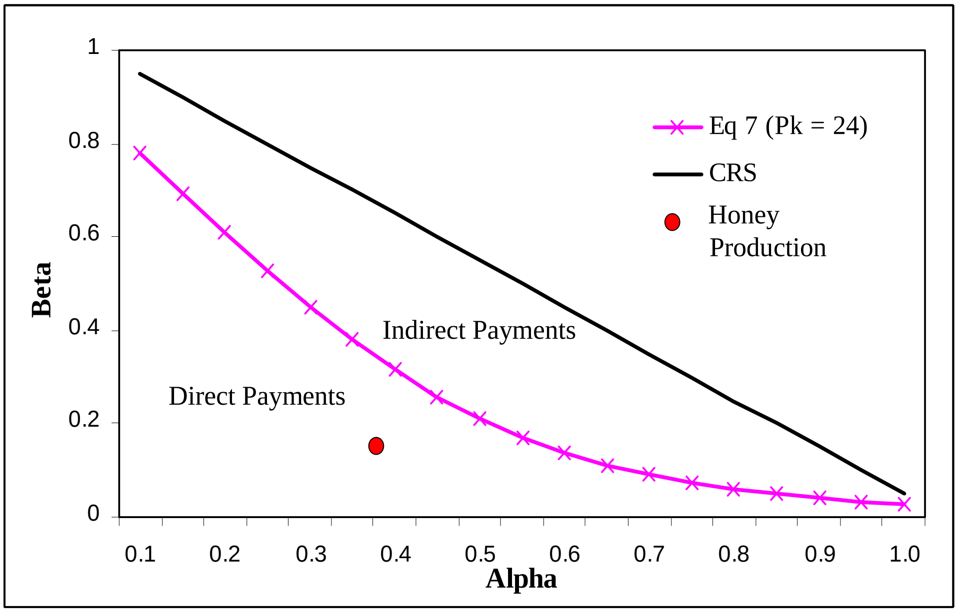

Figure 2: Donor Preferences over Direct and Indirect Payments: Variation with Technological Parameters α and β.

5.2 Discussion

In sum, the analysis illustrates the importance of understanding market and institutional constraints when designing PES policy interventions. PES schemes which endeavour to relax binding constraints can in principle achieve environmental and poverty alleviation objectives simultaneously. In addition, where households are market constrained the cost-effectiveness of PES depends crucially on the specifics of production. This enables the identification of the type of production process that is a likely candidate for indirect interventions. Taking the simple Cobb-Douglas model literally, where production exhibits constant returns to scale or has highly complementary inputs the simulation shows a greater likelihood that the donor will prefer indirect payments which relax constraints. In practice this might occur where the production process is more closely linked to land-use changes, or where production has been shown to be more or less constant returns to scale, such as in agriculture or in forestry (see e.g. Battese and Coelli 1992). In such cases indirect PES for agri-environmental schemes where households face constraints in input or output markets, e.g. in off-farm labour, could be envisaged. Provided constraints can be identified, targeted and effectively relaxed, indirect PES may achieve both poverty reduction and environmental improvements, not either or. Indeed, it appears that this is precisely what happened in the Sloping Lands Conversion Programme in China in which the relaxation of liquidity and off-farm labour market constraints has succeeded in both reducing poverty and providing environmental benefits (Gauvin et al., 2009; Groom et al., 2009; Uchida et al., 2009).

Nevertheless, the analysis indicates that indirect approaches are unlikely to be cost-effective for the donor in the case of forest honey production. In terms of the parameters of the model, stark decreasing returns to scale and weak relationships between capital and forest inputs tend to favour direct PES, despite a severe constraint. Indeed, this finding is made stronger when one considers what is left out of the production function analysis. For instance, to the extent that it is not reflected in the parameter β, the public good nature of forests makes the link between capital and forest even weaker. Ferraro and Simpson (2002) provide a number of convincing additional arguments in favour of direct payments, over and above cost-effectiveness. From this perspective, the prospect of attaining environmental and poverty alleviation objectives simultaneously seems particularly remote. As a policy intervention, overcoming technological constraints in honey production should probably be considered a more cost-effective poverty alleviation strategy than a means of securing environmental improvements.

However, even in the case of forest honey production, indirect PES is efficient in the sense that it generates the lowest deadweight welfare loss. In fact, due to the released quota rent it generates a welfare gain. This means that indirect payments would almost certainly be preferred if side payments were possible. Conceptually, one simple way in which to make this transfer would be for the donor to ask for a contribution towards the costs of relaxing the constraint, so that the donor in effect provides 'matching funds'. In the context of the model, this would be reflected in a reduction in the price paid by the donor, P_K, which is transferred to the recipient. Where indirect payments are efficient it would always be possible to achieve a Pareto improvement and hence, achieve both environmental and poverty alleviation objectives.[26]

Of course, such a strategy ignores the attendant problems associated with organising and bargaining over side payments, as well as other costs associated with each type of payments scheme. Indeed, the axiomatic approach taken here also ignores many other features of the problem. For instance, the assumption of profit maximisation underpins latent demand and the notion of a quota rent. If recipients were satisficing, as considered by Angelson (1999) in relation to deforestation, then the indirect approach would be much less effective in increasing forest land and improving well-being. Also absent from this approach is any clear understanding of the social relationships that are likely to exist between household labour, forests, and capital. For example, in the Madagascar case we note that there is some evidence of local resistance to the use of cash payments in direct PES schemes (see, for example, Pollini 2008; Hockley and Andriamarovololona 2007). One important reason is that some people simply prefer in-kind transfers instead of cash. Other, more straightforward economic reasons include a lack of local markets for products such as for some agricultural inputs and a lack of banking facilities, which may give disincentives for saving. Whether direct or indirect, in-kind payments will be highly effective if they also manage to relax and important constraint. Overall, production analysis considered on its own only sheds limited light on PES policy choice.

In equal measure, although we have offered a means of identifying the constraint, it is rather crude in that it sidesteps the underlying reasons for its existence. In general these undoubtedly include informational issues, institutional dimensions such as land rights and labour market rigidities, and other social concepts such as norms (e.g. Carter and Olinto 2003, Grosjean et al, 2008). We have casually motivated failings in the capital market as underpinning the technological constraint. This is usually framed as an informational problem in which case it may not be realistic to assume that the donor would have better information about the recipient than the institutions which ration credit, and hence would be no better placed to relax this constraint (Ghosh et al., 2000). More generally, there will always be some informational asymmetry between the donor and recipient, which will muddy the waters of PES design and is not considered explicitly here.[27]

Lastly, while a latent demand for joint products from interventions such as eco-tourism and forest honey might already exist, weak property rights and hence lack of markets for so-called environmental services implies the need for market creation. This is one reason for potentially high transaction costs in the creation of demand for environmental services, which, for example, still plague the fast-developing carbon market including schemes that provide direct payments for carbon sequestration in biomass (see van Kooten et al., 2002; Palmer and Silber, 2009). Knowing transaction costs is crucial for comparing relative cost-effectiveness and efficiency in interventions. It could be argued that since indirect payments address an existing, albeit constrained, institutional environment, they circumvent some specific difficulties associated with market creation.

[26] In the general PES literature, note that so-called 'indirect' PES are typically not even classified as such (for example, see Engel et al. 2008). Instead, interventions such as eco-tourism and honey production are rather seen as market-based instruments, although to some extent this is a discussion about semantics.

[27] See Feng (2007) for a contracting model of PES with dual policy goals in a world of asymmetric information.

Without detailed data on the economic, institutional and social environment facing the households under analysis, it becomes difficult to undertake anything but an approximate quantitative analysis. Exploiting the assumptions concerning the production process and household behaviour, and the limited data on prices and quantities, is an attempt to bridge this informational gap. The approach taken here can, at best, be described as a parsimonious representation of the constraints faced in honey production in Madagascar, which avoids any analysis of wider economic, social and institutional issues. While the results point to the importance of technology and market constraints in achieving both poverty alleviation and environmental goals, the design of PES schemes should be informed by a deeper political economy analysis.

6 Conclusion

In this paper, we investigate the market conditions in developing countries under which PES interventions, direct and indirect, to induce conservation may also lead to poverty alleviation. Identifying the market conditions may be an important factor in choice of policy instrument and hence in potential outcomes from intervention. Data collected in the Central Menabe region of Madagascar are used to illustrate the response of technology-constrained households to direct and indirect PES. Specifically, we calibrate a model of forest honey production in which two different technologies of production are employed by households, traditional and semi-modern. Within this limited framework, we compared the cost-effectiveness, efficiency and donor-recipient preferences for direct and indirect PES interventions. Indirect payments involved the relaxation of a technology constraint, which, in the stylised context of the model, is simply a question of supplying modern beehives.

Our results show that where households are technology constrained, the donor and recipient do not agree on cost-effective payments which relax constraints. The technological constraint faced by honey producers is not sufficiently severe to favour relaxing the capital constraint, although they would prefer indirect payments due to the presence of quota rents. As we show the donor's preference for direct payments is primarily due to the the severe decreasing returns to scale that are observed in beekeeping. We also note that the donor's preference is not socially efficient, meaning that if side payments such as matching funding were feasible, the donor could be persuaded to employ indirect payments. More generally, the results are sensitive not only on the severity of the constraint and the costs of relaxing it, but also the extent of diminishing returns and complementarity of inputs. We note that detailed institutional and other context-specific information is required to better understand and challenge the behavioural assumptions underlying our results.

Irrespective of the model approach, it is clear that some production processes are more closely connected to the provision of environmental services than others. Our limited modelling exercise provides some guidance in that regard. This is important given the ongoing and rapid take-up and expansion of PES all over the world. Cost-effective interventions will, for example, be key in the implementation of schemes for Reducing Emissions from Deforestation and Degradation (REDD) (see Stern, 2006; Eliasch, 2008; Palmer and Engel, 2009). How REDD might be implemented on the ground is still a focus of much debate but in principle carbon services could be supplied either directly or indirectly. Furthermore, our discussion of dual policy goals suggests a need for targeting not only with respect to choice of technology but also with respect to space. While macro-level studies suggest a direct correlation between poverty and environment (e.g. Sachs et al., 2009), the empirical evidence at the micro-level suggests that PES is not necessarily benefiting the poor for various reasons including the presence of institutional and other types of constraints (see Engel et al., 2008). Inversely, targetting of the poor may well have reduced the environmental benefits associated with the SLCP in China (Uchida et al., 2009). Nevertheless, where constrained recipients and environmental assets coincide, indirect approaches could well represent both a cost-effective and welfare-enhancing alternative to the highly - feted direct payment approach.

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Appendices

A Constrained and Unconstrained Profit Function

We follow Fulginiti and Perrin (1993) in showing that the constrained and unconstrained profit functions are related in the single input case. The unconstrained profit function is:

$$\Pi^U \left(P_Q, P_F, P_K; z\right) = \max_{K,F} P_Q f\left(F, K\right) - P_F F - P_K K \tag{12}$$

F and K are freely chosen subject to the fixed inputs, z. If K is constrained $\left(K = \bar{K}\right)$, the constrained profit function can be written in terms of the partial profit function as $\Pi^P\left(.\right)$:

$$\begin{aligned} \Pi^C \left(P_Q, P_F, P_K; \bar{K}, z\right) &= \max_{F} P_Q f\left(F, \bar{K}\right) - P_F F - P_K \bar{K} \\ &= \Pi^P \left(P_Q, P_F; \bar{K}, z\right) - P_K \bar{K} \end{aligned} \tag{13}$$

The virtual or shadow price of capital, P_v, is defined as the price that would induce the firm to choose $\bar{K}$, and is a function of the other variables: $P_v = P_v\left(P_Q, P_F; \bar{K}, z\right)$. $\Pi^U\left(.\right)$ can then be written as:

$$\begin{aligned} \Pi^U \left(P_Q, P_F, P_v; z\right) &= \max_{K,F} P_Q f\left(F, K\right) - P_F F - P_K K \\ &= \Pi^P \left(P_Q, P_F; \bar{K}, z\right) - P_v \bar{K} \end{aligned} \tag{14}$$

which gives a formal definition of $P_v : \Pi^u_v = -\bar{K}$[28]. At P_v, Π^U and Π^C are then related as follows: $\Pi^U\left(P_Q, P_F, P_v; z\right) = \Pi^C\left(P_Q, P_F, P_v; \bar{K}, z\right)$ and from (13) and (14) we get:

$$\Pi^C \left(P_Q, P_F, P_K; \bar{K}, z\right) = \Pi^U \left(P_Q, P_F, P_v; z\right) + \left(P_v - P_K\right) \bar{K} \tag{15}$$

It is straightforward to show the following relationships which are used in the text:

$$\Pi^c_F = \Pi^u_F + \left(\Pi^u_v - \bar{K}\right) \frac{\partial P_v}{\partial P_F} = \Pi^u_F \tag{16}$$

$$\Pi^c_{\bar{K}} = \left(P_v - P_K\right) + \left(\Pi^u_v - \bar{K}\right) \frac{\partial P_v}{\partial \bar{K}} = \left(P_v - P_K\right) \tag{17}$$

The Hessian of the constrained profit function in terms of the unconstrained for inputs F and $\bar{K}$ are:

$$\Pi^c_{\bar{K}\bar{K}} = -\left(\Pi^u_{vv}\right)^{-1} \tag{18}$$

$$\Pi^c_{F\bar{K}} = -\Pi^u_{Fv}\left(\Pi^u_{vv}\right)^{-1} \tag{19}$$

$$\Pi^c_{FF} = \Pi^u_{FF} + \Pi^u_{Fv}\left(\Pi^u_{vv}\right)^{-1}\Pi^u_{vF} \tag{20}$$

Similar results would pertain in relation to an output constraint.

[28] Where $\Pi^u_c = \frac{\partial \Pi^u}{\partial P_V}$.

B Efficiency of Direct and Indirect Payments: Equation (5)

A second-order approximation for the change in profits when additional forest is provided by direct means is given by (dropping z for brevity):

$$\Pi^C\left(P_Q, P_F + dP_F, P_K; \bar{K}\right) \approx \Pi^C\left(P_Q, P_F, P_K; \bar{K}\right) + \Pi^C_F dP_F + \frac{1}{2}\Pi^C_{FF}\left(dP_F\right)^2$$

The total cost is calculated by subtracting from this expression the overall cost of the direct payments intervention to the donor. The total cost is given by the right-hand side of the following expression, where F_0 is the initial level of forest cover. The right-hand side is the deadweight loss:[29]

$$\Pi^C\left(P_Q, P_F + dP_F, P_K; \bar{K}\right) - \Pi^C\left(P_Q, P_F, P_K; \bar{K}\right) + \left(F_0 + \frac{\partial F}{\partial P_F} dP_F\right) dP_F \approx \frac{1}{2}\frac{\partial F}{\partial P_F}\left(dP_F\right)^2 \tag{21}$$

The same procedure for indirect payments to relax capital constraints yields:

$$\begin{aligned}\Pi^C\left(P_Q, P_F, P_K; \bar{K} + d\bar{K}\right) &\approx \Pi^C\left(P_Q, P_F, P_K; \bar{K}\right) + \Pi^C_{\bar{K}} d\bar{K} + \frac{1}{2}\Pi^C_{\bar{K}\bar{K}}\left(dK\right)^2 \\ &\approx \Pi^C\left(P_Q, P_F, P_K; \bar{K}\right) + \left(P_v^0 - P_K\right) dK + \frac{1}{2}\Pi^C_{\bar{K}\bar{K}}\left(dK\right)^2\end{aligned}$$

Subtracting the resource cost $P_K dK$, yields the net profits:[30]

$$\Pi^C\left(P_Q, P_F, P_K; \bar{K} + dK\right) - \Pi^C\left(P_Q, P_F, P_K; \bar{K}\right) - P_K dK \approx \frac{1}{2}\frac{\partial P_v}{\partial \bar{K}}\left(dK\right)^2 + \left(P_v^0 - P_K\right) dK \tag{22}$$

where P_v^0 is the initial virtual price of capital at $K = \bar{K}$. The right-hand side of (21) is area a in Figure 1. The right-hand side of (22) is area b and c in Figure 1. Expression (5) is obtained by taking the right-hand side of (22) from the right-hand side of (21):

$$\frac{1}{2}\left[\frac{\partial F}{\partial P_F}\left(dP_F\right)^2 - \frac{\partial P_v}{\partial K}\left(dK\right)^2\right] - \left(P_v^0 - P_K\right) dK \tag{23}$$

Note that the change in the virtual price of capital as a result of the indirect payments, dP_v^I, is given by $dP_v^I = \frac{\partial P_v}{\partial K} dK$ and the change in the virtual price as a result of the direct payments is given by $dP_v^D = -\frac{dP_F}{dK}$.[31] Via substitution of (23):

$$\frac{1}{2}\left[-dP_v^D dK - dP_v^I dK\right] - \left(P_v^0 - P_K\right) dK$$

which is one step from (5).

[29] This is equivalent to expression A4 in Ferraro and Simpson (2002), corrected only by the absence of the minus sign on the right-hand side.

[30] Note that $\Pi^C_{\bar{K}} = (P_v - P_K)$ and $\Pi^C_{\bar{K}\bar{K}} = \frac{\partial P_v}{\partial \bar{K}}$ in the case of a constrained input (Fulginiti and Perrin, 1993).

[31] The laborious algebra is as follows: $dP_v^D = \frac{\partial P_v}{\partial P_F} dP_F$, which noting equation (17) and using symmetry can be written as $dP_v^D = \Pi^C_{F\bar{K}} dP_F = -\frac{\Pi^U_{Fv}}{\Pi^U_{vv}} dP_F$. Given (4) this can be written as $dP_v^D = -\frac{dP_F}{dK}$. Details can be found in Fulginiti and Perrin (1993, p99).

C The NGO's Preferences: Equation (7)

The NGO prefers direct payments if $-dP_F F < P_K dK$. Noting from (3) and (4) that $dP_F = -\frac{1}{\Pi^C_{FF}}$ and $dK = \frac{\Pi^U_{vv}}{\Pi^U_{Fv}}$, this becomes:

$$\frac{F}{\Pi^C_{FF}} = \frac{-F}{\partial F^C / \partial P_F} < P_K \frac{\Pi^U_{vv}}{\Pi^U_{Fv}} = P_K \frac{-\partial K^U / \partial P_v}{-\partial F^U / \partial P_v}$$

Taking the reciprocal and multiplying both sides by P_F gives:

$$-\frac{\partial F^C}{\partial P_F} \frac{P_F}{F} > \frac{-\partial F^U / \partial P_v}{-\partial K^U / \partial P_v} \frac{P_F}{P_K}$$

Given symmetry of the unconstrained profit function we have: $\partial F^U / \partial P_v = \partial K^U / \partial P_F$. Inserting this, multiplying top and bottom by K and rearranging yields (7):[32]

$$\frac{\eta^U_{KF}}{\eta^C_{FF}} < \eta^U_{KK} + \frac{1}{K} \frac{\partial K^U}{\partial P_v} \left(P^0_v - P_K \right)$$

D Sensitivity of Donor Preferences to the price of capital, P_K

[32] Note that the numerator of the RHS of (7) is equal to $-\frac{\partial K^U}{\partial P_v} \frac{P_K}{K}$, which would be the point elasticity at P_v but for the fact that it is evaluated at P_K. Noting that $P_K = (P_v + P_K - P_v)$ the numerator becomes:

$$\eta^U_{KK} + \frac{1}{K} \frac{\partial K^U}{\partial P_v} (P_v - P_K)$$

From this point it is easy to get (7).

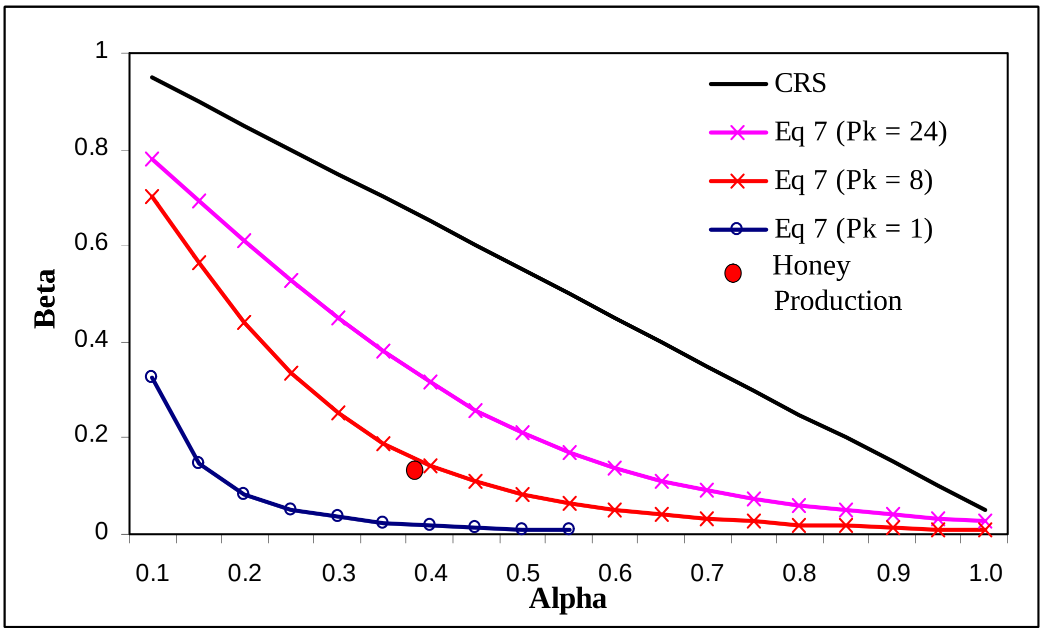

Figure 3: Donor's Preferences over Indirect and Direct Payments: Technology (β and α) and the Price of Capital (P_K).