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MECHANISM DESIGN FOR BIODIVERSITY CONSERVATION IN DEVELOPING COUNTRIES

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Mechanism Design for Biodiversity Conservation in Developing Countries*

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Abstract

In this paper the design of a voluntary incentive scheme for the provision of ecosystem services is considered, having in mind the forested areas in developing countries where a governmental agency plans to introduce a set-aside policy. Payments are offered to the landowners to compensate the economic loss for not converting land to agriculture. The information asymmetry between the agency and the landowners on the opportunity cost of conservation gives incentive to the landowners to misreport their own "type". A principal - agent analysis is developed, adapted and extended to capture real issues concerning conservation programs in developing countries. We show that the information asymmetry may seriously impact on the optimal scheme performance and, under certain conditions, may lead to pay a compensation even if any additional conservation is induced with respect to that in absence of the scheme.

KEYWORDS: biodiversity conservation, asymmetric information, mechanism design.

JEL CLASSIFICATION: D82, D86, Q57, Q58.

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1 Introduction

In the last decades the Payments for the provision of Ecosystem Services (hereafter, PES) have become an increasingly popular instrument to induce the provision of ecosystem services on private lands.[1] The target for most of the land managed under PES programs has usually been the conservation of biodiversity and the soil protection (Salzman, 2005; Ferraro, 2001; Ferraro and Kiss, 2002; Pagiola et al., 2002). Under a PES program a contract is usually proposed by a governmental agency to a landowner. The landowner sets aside a part of her own land and receives a compensation for the economic loss suffered. The contract is designed to allow for the voluntary participation of the landowner to the program and specifies the extent of land that should be conserved and the compensation paid for the environmental service provided. To guarantee a voluntary participation the payment should be at least equal to the landowners' opportunity cost and no higher than the value of the benefit provided.

The landowners know their property and the opportunity cost of managing it for environmental services better than the governmental agency. Landowners could then have incentive to misreport their true type in order to be over compensated. This opportunistic behaviour produces an additional burden for the agency and impacts on the total level of conservation which may be induced through a program becoming a serious issue when funds for conservation are limited and/or are costly raised through distortionary taxation. This problem is common to a number of other situations where agents with different cost opportunity type may take advantage of their private information and the principal searches to differentiate them through a proper contract scheme. In these cases mechanism design theory can be used to design contract scheme which induces truth-telling (Mirrlees 1971; Groves, 1973; Dasgupta, Hammond and Maskin, 1979; Baron and Myerson, 1982; Guesnerie and Laffont, 1984). This is what has been also broadly done to deal with information failures impacting on the design of conservation contracts (Smith and Shogren, 2002; Wu and Babcock, 1996; Smith, 1995; Goeschl and Lin, 2004).

In the reality despite the fact that optimal incentive schemes could be

[1] A well known example is given by the PSA (Pagos por Servicios Ambientales) program in Costa Rica (FONAFIFO, 2000; Pagiola et al., 2002; Salzman, 2005). For other examples http://www2.gsu.edu/~wwwcec/special/ci/index.html.

designed, PES programs are usually general subsidy schemes.[2] A general subsidy scheme is surely easier to implement but it allocates sub-optimally the funds for conservation in that overpays[3] landowners which misreport their cost opportunity[4] type.

The aim of this paper is to address such concern and design a voluntary incentive scheme for habitat conservation in developing countries where a substantial extent of land is still forested but "slash and burn" practices have become intense.

We investigates the adverse selection issue due to the information asymmetry between the governmental agency and the landowner on the environmental characteristics of each property. This set of characteristics affects the land agricultural productivity and determine the opportunity cost of each unit of land conserved. We are clearly aware that reality is even more complex for the presence of moral hazard in the contract compliance and for the asymmetry in gathering information about conservation costs but we prefer to abstract from these issues and work on a simpler model.[5]

We model the agricultural activity undertaken after land conversion as a risky activity suffering exogenous shocks which negatively affects the landowner's crop yield. This is an aspect which has not been considered in the previous contributions on this topic but that is in our opinion very relevant in that risk affects the landowner private allocation choice and consequently the actual cost opportunity of conservation.[6] Moreover, this consideration can be even more important in developing countries where the agricultural activity is still primitive and the investment in technology is low.

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[2] This is the case for example for the PSA program in Costa Rica where each land unit conserved is paid the same amount and any landowner in the country is allowed to participate and choose the extent of land to be conserved (Pagiola et al., 2004).

[3] This has probably been the case in Costa Rica where the compensation paid has been quite attractive and a number of applications to the program were not considered because of funding limits (Pagiola et al., 2004).

[4] By principle also the different levels of benefit provided by the service should be taken into account. But as in the case of biodiversity conservation, such benefit is extremely difficult to assess. In contrast, to collect information on and estimate the landowner's opportunity cost may be easier and less costly.

[5] See White (2002) for the moral hazard problem and Goeschl and Lin (2004) for the asymmetry in the information gathering.

[6] There have been in fact no studies up to date assessing how much land managed under a conservation program would have been cleared in the absence of the program.

The set-up of our model is completed by first, assuming that the level of conservation pursued by the governmental agency through the conservation program is not fixed ex-ante but results from the social welfare maximization, second, assuming that the private level of conservation is not necessarily zero but it is optimally determined by the landowner according to the expected profit associated to converting land and third, introducing as in the paper by Motte et al. (2004) a constraint on the surface conserved to control for the effectiveness of the policy.[7] The purpose of this constraint is to control for a policy perverse effect which could induce landowners to clear more forest than they would have cleared without a contract.

In this frame a program consistent with the conservation target is designed to guarantee voluntary participation and truthful revelation of land opportunity cost. We show that the information asymmetry may seriously impact on the optimal second-best scheme leading under certain conditions to pooling types. First best conservation can only be attained if raising funds for the transfers comes at no cost. We also verify that even if any additional conservation is induced with respect to the extent privately undertaken a compensation must be paid in some cases to landowners. This is done only to induce them to reveal their private information and limit the information rent that must be paid to other types. We finally prove that the program designed is the optimal or best feasible contract scheme available and that social surplus under a general subsidy conservation program cannot be higher than under the optimal second best conservation program.

The structure of the paper is the following: in section 2, the landowner and governmental agency's preferences are presented; the private allocation in the absence of a conservation program and the first best allocation with a conservation program in place are presented and discussed. In section 3, the second best outcome is derived and its properties are discussed. Section 4 proposes a parametric example of the optimal conservation program at work. Section 5 concludes.

[7] In Motte et al. (2004) the information asymmetry is on the individual cost of clearing effort. A "policy consistency" constraint is introduced in the standard principal-agent problem to restrict the set of incentive compatible contract schedules to the one where the conservation undertaken under the CP is at least equal to that without CP.

2 The basic set-up

We assume that each landowner owns $\overline{A}$ units of land and that each plot is in its pristine natural state. Each landowner's plot is of the same size but not necessarily has the environmental characteristics[8] of the one owned by another landowner. On these private lands the governmental agency (hereafter, GA) plans to preserve some critical habitat for biodiversity conservation and to induce that proposes a voluntary contract scheme. According to the scheme, each landowner is paid to set aside a units of her plot for conservation. We further assume that the GA and the landowners are risk-neutral agents and that the funding of the transfers is raised as standard by taxation.

2.1 Landowner and Government Agency's preferences

Each landowner's plot is characterized by a set of characteristics, such as soil quality, soil erosion and water and distance to market. We use a scale index θ to represent these characteristics (Wu and Babcock, 1996). This parameter varies among landowners and defines their type. We assume that the agricultural productivity of the plot is positively related to θ. The index θ is private information of the landowner. However, it is common knowledge that it is drawn from the interval $\Theta = \left[\underline{\theta}, \overline{\theta}\right]$ with a cumulative distribution function $F(\theta)$ and a density function $f(\theta)$. The density function is assumed to be strictly positive on the support Θ. Moreover, $f(\theta)$ satisfies the regularity conditions[9] such that $\frac{\partial[F(\theta)/f(\theta)]}{\partial\theta} \geq 0$.

Crop yield to the landowner is represented by

$$(1 - v)\, Y\left(\overline{A} - a, \theta\right) \tag{1}$$

where $\overline{A} - a$ is the surface cultivated, θ is the land type and v is a random shock which may reduce the crop production and could be related to the technologically primitive "slash and burn" agricultural practice that is typical in developing countries still forested areas.[10] We assume that v belongs to

[8] Hereafter, we will simply use "type".

[9] Most parametric single-peak densities meet this sufficient condition (Bagnoli and Bergstrom, 1989).

[10] However, it could be assumed a constant yield and model in the same simple way a shock on the price of the crop due to changing market conditions. This could be done at

the set $V = \{\underline{v}, \overline{v}\}$ where $0 \leq \underline{v} < \overline{v} \leq 1$ and it is equal to $\underline{v}$ or $\overline{v}$ with probability q and $1-q$ respectively. Therefore, the expected crop yield is

$$\begin{aligned} q(1-\underline{v})\,Y\,\left(\overline{A}-a,\theta\right) + (1-q)(1-\overline{v})\,Y\,\left(\overline{A}-a,\theta\right) \\ = \left[1-\overline{v}+q(\overline{v}-\underline{v})\right] Y\,\left(\overline{A}-a,\theta\right) \end{aligned} \quad (2)$$

Assume that the production is increasing and concave in the units of land converted, increasing in θ and that the marginal product with respect to land is increasing in the land type. This is equivalent to following set of assumptions: $Y_1 > 0$**,** $Y_{11} < 0$**,** $Y_2 > 0$ and $Y_{12} > 0$ where $Y_1 = \partial Y/\partial\left(\overline{A}-a\right)$, $Y_2 = \partial Y/\partial\theta$, $Y_{11} = \partial^2 Y/\partial(\overline{A}-a)^2$, $Y_{12} = \partial^2 Y/\partial(\overline{A}-a)\theta$**.**

In the absence of a conservation program (hereafter, CP), the expected profits to each landowner's $\overline{A}-a$ units of land are represented by

$$\pi\left(\overline{A}-a,\theta\right) = p\left[1-\overline{v}+q(\overline{v}-\underline{v})\right] Y\left(\overline{A}-a,\theta\right) - c\left(\overline{A}-a\right) \quad (3)$$

where p is the price of the product and c is the private cost for converting a unit of land, i.e. the cost of clearing the new plot and settle it.

We assume as in Motte et al. (2004) that given the abundance of forested land convertible the constraint on land availability is non binding. Other factors like labour and other inputs, here represented by c,are scarcer and more costly for the landowner. This means that even in the absence of a CP the landowner do not convert all the available land $(a > 0)$. This is often the case in developing countries, where landowners are often credit-constrained and can afford the conversion cost just up to a certain extent of land.

In this situation, each landowner maximizes her expected rents with respect to the converted surface $(\overline{A}-a)$

$$\max_{\overline{A}-a} \pi\left(\overline{A}-a,\theta\right) = p\left[1-\overline{v}+q(\overline{v}-\underline{v})\right] Y\left(\overline{A}-a,\theta\right) - c\left(\overline{A}-a\right)$$

Rearranging the first order condition (hereafter, foc)

$$p\left[1-\overline{v}+q(\overline{v}-\underline{v})\right] Y_1\left(\overline{A}-a,\theta\right) = c \quad (4)$$

it follows that

$$Y_1\left(\overline{A}-a,\theta\right) = \frac{c}{p\left[1-\overline{v}+q(\overline{v}-\underline{v})\right]}$$

no cost and keeping the model practically intact.

The surface to be cultivated is determined equalising the expected marginal land productivity with the private conversion cost. Note that being $Y_{11} < 0$ the surface converted increases as the private conversion cost, c/p, decreases. The crop yield depends on the magnitude of the exogenous shock and its likelihood and as one can easily check in (4) the landowner convert more land as the expected yield increases.

Define by $\overline{A} - \widehat{a}(\theta)$ the private optimal level of conversion and substitute it into the expected profit function to derive the level of expected profit

$$\pi\left(\overline{A} - \widehat{a}(\theta), \theta\right) = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y\left(\overline{A} - \widehat{a}(\theta), \theta\right) - c\left(\overline{A} - \widehat{a}(\theta)\right) \quad (5)$$

If the GA announces a CP then a voluntary contract schedule $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$ is proposed to landowners. In the contract $a(\theta)$ represent the surface of land type θ to be conserved and $T(\theta)$ is the relative transfer. If the landowner accepts the contract then her expected program rents are given by

$$\begin{aligned} \Pi\left(\overline{A} - a(\theta), \theta\right) &= \pi\left(\overline{A} - a(\theta), \theta\right) + T(\theta) \quad (6) \\ &= p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y\left(\overline{A} - a(\theta), \theta\right) - c\left(\overline{A} - a(\theta)\right) + T(\theta) \end{aligned}$$

The GA's objective[11] is the maximization of the social surplus, W, with respect to the pair $[a(\theta), T(\theta)]$. Social surplus is defined as

$$W = B(a(\theta)) - (1 + \lambda) T(\theta) + \Pi\left(\overline{A} - a(\theta), \theta\right) \quad (7)$$

where λ is the shadow cost of public funds.[12] The function $B(a(\theta))$ is the social benefit deriving from setting aside $a(\theta)$ units of land. Social benefit may include the value of good and services such as flood control, carbon sequestration, erosion control, wildlife habitat, biodiversity conservation, recreation and tourism and option and existence value associated to the habitat conserved. We assume that $B(a(\theta))$ is increasing and strictly concave in its argument and that $\lambda \geq 0$.

[11] The multi-agent problem faced by the GA can be analysed as a single-agent problem repeated n times (Smith and Shogren, 2002).

[12] Funds have been raised by taxes and this parameter reflects the marginal deadweight loss from (distortionary) taxation (Wu and Babcock, 1996).

2.2 Conservation in First Best

We set up the standard mechanism design problem to derive as solution the optimal CP. As standard we first solve the problem in a first best situation where there is perfect information and the GA knows each landowner's type. The definition of the properties of the first best solution will be useful later when we will refer to it as a benchmark. In this case the GA's problem is given by:

$$\max_{a(\theta),T(\theta)} W = B\left(a\left(\theta\right)\right) - \left(1+\lambda\right) T\left(\theta\right) + \Pi\left(\overline{A} - a\left(\theta\right), \theta\right) \tag{8}$$

$$\begin{aligned} & s.t. \\ \Pi\left(\overline{A} - a\left(\theta\right), \theta\right) & \geq \pi\left(\overline{A} - \widehat{a}\left(\theta\right), \theta\right) \\ a\left(\theta\right) & \geq \widehat{a}\left(\theta\right) \qquad\qquad for\ all\ \theta \in \left[\underline{\theta}, \overline{\theta}\right] \end{aligned}$$

The first constraint is the individual rationality constraint which ensures voluntary participation to the program. It guarantees that the landowners are at least not worse off accepting the contract than not accepting it. This constraint is type-dependent in that the return accruing to the landowner not participating to the CP is related to the productivity of her own plot. The second constraint is instead introduced to control that each landowner conserves at least the same surface of land that she would have conserved without contract. Not introducing this constraint, the CP, could end up providing the perverse incentive to convert more land.

Proposition 1 *In first best the surface allocated to agriculture within the CP is less than without the CP for every* $\theta \in \left[\underline{\theta}, \overline{\theta}\right]$.

See appendix A.1 for the proof.

From the foc of the maximization problem it comes out that if $a\left(\theta\right) = a^{FB}\left(\theta\right)$ the following relation must hold if

$$p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - a\left(\theta\right), \theta\right) = c + \frac{B'\left(a\left(\theta\right)\right)}{\left(1+\lambda\right)} \tag{9}$$

The GA maximizes its objective function with respect to $a\left(\theta\right)$ when accepting the contract the landowner equalizes her expected land marginal productivity with her private cost of clearing land plus the negative externality generated by converting. The surface converted still depends on the private clearing cost and on the expectations in terms of crop yield. The risk in the production can have important consequences in landowner decisions and it has to be considered when a CP is designed. Internalizing the social cost of her action the landowner reduces the surface of land converted. Note in (9) that the marginal social benefit is adjusted by $(1+\lambda)$ and this reflects the existence of a trade off between the cost of raising funds for the payments and the marginal benefit from conservation. In fact, as λ increases the surface cultivated is larger and less conservation is achieved.

The transfer is paid to each landowner accordingly to her type and is given by

$$T^{FB}(\theta) = \pi\left(\overline{A} - \widehat{a}(\theta), \theta\right) - \pi\left(\overline{A} - a^{FB}(\theta), \theta\right) \tag{10}$$

3 Mechanism under adverse selection

The GA announces the voluntary contract scheme $\left\{[a(\theta), T(\theta)];\ \underline{\theta} \leq \theta \leq \overline{\theta}\right\}$. Now, there is no perfect information and the landowners have more information about their type than the GA which only knows the types distribution, $F(\theta)$. In this context the first-best contract schedule may not be incentive compatible and there could be incentive for some landowners to mimic and earn a positive information rent. Hence, the contract schedule should be designed such that for each landowner it is optimal to report the land type truthfully.[13] The participation must be voluntary and after observing the contract schedule proposed, each landowner chooses whether to enter or not into the CP.

To induce truth-telling an incentive compatibility constraint has to be added to the principal-agent problem. This will restrict the set of feasible contract schedules and the resulting optimal CP will be a second best solution.

If type-θ landowner chooses the contract designed for type-$\widetilde{\theta}$ landowners, $[a(\widetilde{\theta}), T(\widetilde{\theta})]$, her expected program rents are

$$\Pi(\overline{A} - a(\widetilde{\theta}), \theta) = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y\left(\overline{A} - a(\widetilde{\theta}), \theta\right) - c\left(\overline{A} - a(\widetilde{\theta})\right) + T(\widetilde{\theta}) \tag{11}$$

[13] In addition to be voluntary the CP mechanism must satisfy a truth-telling condition (Dasgupta, Hammond and Maskin, 1979).

Instead, if she chooses the schedule designed for her type, $[a(\theta), T(\theta)]$,her expected program rents are

$$\Pi\left(\overline{A}-a(\theta),\theta\right)=p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y\left(\overline{A}-a(\theta),\theta\right)-c\left(\overline{A}-a(\theta)\right)+T(\theta) \tag{12}$$

A contract schedule $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$ satisfies the incentive compatibility constraint if and only if

$$\Pi\left(\overline{A}-a(\theta),\theta\right)\geq\Pi(\overline{A}-a(\widetilde{\theta}),\theta),\quad for\ all\ \theta\ and\ \widetilde{\theta}\in\left[\underline{\theta},\overline{\theta}\right] \tag{13}$$

This means that type-θ landowners always prefer $[a(\theta), T(\theta)]$ to all other available contract schedules. Voluntary participation is instead guaranteed imposing as above in the first best case the incentive rationality constraint

$$\Pi\left(\overline{A}-a(\theta),\theta\right)\geq\pi\left(\overline{A}-\widehat{a}(\theta),\theta\right) \tag{14}$$

Definition 1 *A CP is feasible if it satisfies both the incentive compatibility constraint and the individual rationality constraint.*

Under asymmetric information the GA's problem is then given by

$$\begin{aligned}
\max_{a(\theta),T(\theta)} E_\theta[W] &= \int_{\underline{\theta}}^{\overline{\theta}}[B(a(\theta))+\pi\left(\overline{A}-a(\theta),\theta\right)-\lambda T(\theta)]f(\theta)\,d\theta \\
&\quad s.t. \\
\Pi\left(\overline{A}-a(\theta),\theta\right) &\geq \pi\left(\overline{A}-\widehat{a}(\theta),\theta\right) \\
\Pi\left(\overline{A}-a(\theta),\theta\right) &\geq \Pi(\overline{A}-a(\widetilde{\theta}),\theta) \\
a(\theta) &\geq \widehat{a}(\theta) \qquad\qquad for\ all\ \theta\in\left[\underline{\theta},\overline{\theta}\right]
\end{aligned} \tag{15}$$

Now, we rearrange the incentive rationality and compatibility constraints and restate (15) in order to derive and describe the properties of the optimal second best contract schedule (see the appendix for the proofs).

Proposition 2 *A contract schedule $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$ is incentive compatible if and only if*

(a) $a'(\theta) \leq 0$

(b) $T'(\theta) = \left\{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_1\left(\overline{A}-a(\theta),\theta\right) - c\right\}a'(\theta)$

The differential equation stated by the first condition (a) and the monotonicity constraint (b) define the local incentive constraints set, which ensures local truth-telling and completely characterizes a truthful direct revelation mechanism[14] (Laffont and Martimort, 2002).

Condition (a) simply states that an incentive compatible program requires to conserve more units of land where land productivity is low. The landowner's private land allocation is defined by $Y_1\left(\overline{A}-a,\theta\right) = \frac{c}{p[1-\overline{v}+q(\overline{v}-\underline{v})]}$ while under CP in that there is more conservation $Y_1\left(\overline{A}-a\left(\theta\right),\theta\right) \geq \frac{c}{p[1-\overline{v}+q(\overline{v}-\underline{v})]}$. Hence, from condition (b) it follows $T'\left(\theta\right) \leq 0$. This means that under an incentive compatible CP the GA must lower total transfers as land productivity increases. Otherwise, every landowner would have an incentive to mimic the highest land type in that for this type a larger compensation would be paid conserving less (condition a). Instead, the existence of this trade-off should reduce the incentive to misreport. However, even if the total transfer decreases with θ, the highest type landowner must end up earning larger total rents because otherwise she would mimic a lower type choosing the best combination between contract requirement and relative compensation (see appendix A.3).

Proposition 3 *For any incentive compatible CP, the individual rationality constraint is satisfied for all θ when*

$$\Pi\left(\overline{A}-a\left(\overline{\theta}\right),\overline{\theta}\right)-\pi\left(\overline{A}-\widehat{a}\left(\overline{\theta}\right),\overline{\theta}\right)\geq 0 \tag{16}$$

Provided that it holds, this is sufficient condition for all the land types. This means that if the highest type enters into the CP, all the other types may do the same in that their total rents are not reduced.

[14] In the appendix we show that the landowner neither lie globally and that the local incentive constraints imply also global incentive constraints.

Proposition 4 *The GA's problem in equation (15) can be reformulated as follows:*

a)

$$\max_{a(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} \Phi\left[a(\theta), \theta\right] f(\theta)\, d\theta$$
$$s.t.$$
$$a'(\theta) \leq 0$$
$$a(\theta) \geq \widehat{a}(\theta) \tag{17}$$

where

$$\Phi\left[a(\theta), \theta\right] = \frac{B(a(\theta))}{(1+\lambda)\left[1-\overline{v}+q(\overline{v}-\underline{v})\right]} + pY\left(\overline{A}-a(\theta), \theta\right) + \\ -\frac{c\left(\overline{A}-a(\theta)\right)}{\left[1-\overline{v}+q(\overline{v}-\underline{v})\right]} + \frac{\lambda}{(1+\lambda)} pY_2\left(\overline{A}-a(\theta), \theta\right) \frac{F(\theta)}{f(\theta)}$$

b) *Given the optimal conservation schedule, $a^{SB}(\theta)$, derived from (17), the optimal transfer schedule, $T^{SB}(\theta)$, is defined by*

$$T^{SB}(\theta) = T^{SB}(\overline{\theta}) + \tag{18}$$
$$-\int_{\theta}^{\overline{\theta}} \left\{p\left[1-\overline{v}+q(\overline{v}-\underline{v})\right] Y_1\left(\overline{A}-a^{SB}(\xi), \xi\right) - c\right\} a^{SB\prime}(\xi) d\xi$$

where $T^{SB}(\overline{\theta})$ is the minimum transfer such that (16) holds.

The problem in (15) may be solved in three steps. At first, determine $a^{SB}(\theta)$ solving the problem in (17). Second, minimize $\Pi\left(\overline{A}-a^{SB}\left(\overline{\theta}\right), \overline{\theta}\right)$ subject to (16) with respect to $T(\overline{\theta})$. Third, substitute $a^{SB}(\theta)$ and $T^{SB}(\overline{\theta})$ in (18) and compute the optimal transfer schedule.

3.1 Analysis of the optimal Conservation Program

We characterize some of the properties of the solution to (17) through the analysis of the constraints introduced into the problem. First, let start with the perverse incentive constraint taking apart for the moment the monotonicity constraint. The problem in (17) can be represented by the following Lagrangian:

$$L = \int_{\underline{\theta}}^{\overline{\theta}} \Phi \left[a(\theta), \theta \right] f(\theta)\, d\theta + \phi(\theta)\left(a(\theta) - \widehat{a}(\theta) \right)$$

Under imperfect information the necessary conditions for an optimum include:

$$\frac{\partial L}{\partial a(\theta)} = \frac{B'(a(\theta))}{(1+\lambda)\left[1-\overline{v}+q(\overline{v}-\underline{v})\right]} - pY_1\left(\overline{A}-a(\theta),\theta\right) +$$

$$+\frac{c}{\left[1-\overline{v}+q(\overline{v}-\underline{v})\right]} - \frac{\lambda}{(1+\lambda)} pY_{12}\left(\overline{A}-a(\theta),\theta\right)\frac{F(\theta)}{f(\theta)} + \phi(\theta) = 0 \quad \text{(L.1)}$$

$$\phi(\theta)\left(a(\theta)-\widehat{a}(\theta)\right) = 0, \quad \phi(\theta) \geq 0 \quad \text{(L.2)}$$

Consider an interval $[\theta_1, \theta_2] \subseteq \left[\underline{\theta}, \overline{\theta}\right]$ with $\theta_1 < \theta_2$ and suppose $a(\theta) = \widehat{a}(\theta)$ and $\phi(\theta) > 0$.Substituting (5) into $(L.1)$

$$\phi(\theta) = -\frac{B'(\widehat{a}(\theta))}{(1+\lambda)\left[1-\overline{v}+q(\overline{v}-\underline{v})\right]} + \frac{\lambda}{(1+\lambda)} pY_{12}\left(\overline{A}-\widehat{a}(\theta),\theta\right)\frac{F(\theta)}{f(\theta)} \quad (19)$$

Note that when $\theta = \underline{\theta}$, $F(\underline{\theta}) = 0$ and considering that $B'(a(\theta)) > 0$ by assumption

$$\phi(\theta) = -\frac{B'(\widehat{a}(\underline{\theta}))}{(1+\lambda)\left[1-\overline{v}+q(\overline{v}-\underline{v})\right]} < 0$$

By contradiction we can then prove that at least for $\theta = \underline{\theta}$, $\phi(\theta)$ must be null and the constraint is not binding. This means that in lowest type land more conservation is undertaken under the CP than without it. It follows that $\underline{\theta} < \theta_1$.

To analyze what happens in the rest of the interval one should study the derivative of $\phi(\theta)$

$$\phi'(\theta) = -\frac{B''(\widehat{a}(\theta))}{(1+\lambda)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}\widehat{a}'(\theta) + \tag{20}$$
$$-\frac{\lambda}{(1+\lambda)}\left[pY_{112}\left(\overline{A}-\widehat{a}(\theta),\theta\right)\frac{F(\theta)}{f(\theta)}\widehat{a}'(\theta) - pY_{122}\left(\overline{A}-\widehat{a}(\theta),\theta\right)\frac{F(\theta)}{f(\theta)}+\right.$$
$$\left.-pY_{12}\left(\overline{A}-\widehat{a}(\theta),\theta\right)\frac{\partial\left[F(\theta)/f(\theta)\right]}{\partial\theta}\right]$$

At this point, given that any particular form has been assumed for the functions in the program $\phi'(\theta)$ can take both signs in $[\theta_1, \theta_2]$. This implies that the perverse incentive constraint may be binding somewhere.

From (19) $\phi(\theta) \geq 0$ when

$$\lambda p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{12}\left(\overline{A}-\widehat{a}(\theta),\theta\right)\frac{F(\theta)}{f(\theta)} \geq B'(\widehat{a}(\theta)) \tag{21}$$

The intuition behind (21) is straightforward, if the marginal cost of information (LHS) is greater then the marginal social benefit from conservation (RHS) then the extent of conservation under CP is equalivalent to that privately undertaken. If (21) does not hold then additional conservation can be induced implementing a CP. If this is the case then $a(\theta) > \widehat{a}(\theta)$ and $\phi(\theta) = 0$. It follows that the optimal $a(\theta)$ must satisfy the following condition:

$$\frac{B'(a(\theta))}{(1+\lambda)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]} - pY_1\left(\overline{A}-a(\theta),\theta\right) + \frac{c}{\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}+$$
$$-\frac{\lambda}{(1+\lambda)}pY_{12}\left(\overline{A}-a(\theta),\theta\right)\frac{F(\theta)}{f(\theta)} = 0 \tag{22}$$

Now, we focus on the monotonicity constraint. From condition (a) in Proposition 2 an optimal second best CP requires $a^{SB\prime}(\theta) \leq 0$. It can be proved that when $a^{SB}(\theta) = \widehat{a}(\theta)$ the monotonicity constraint is always satisfied on the interval $[\theta_1, \theta_2]$ (see the appendix A.6). Let consider then the case $a^{SB}(\theta) > \widehat{a}(\theta)$.

Differentiating (22) and solving for $a^{SB\prime}(\theta)$:

$$a^{SB\prime}(\theta) = \frac{pY_{12}\left(\overline{A}-a^{SB}(\theta),\theta\right)+\upsilon\frac{F(\theta)}{f(\theta)}pY_{122}\left(\overline{A}-a^{SB}(\theta),\theta\right)+\upsilon pY_{12}\left(\overline{A}-a^{SB}(\theta),\theta\right)\frac{\partial[F(\theta)/f(\theta)]}{\partial\theta}}{\omega B''(a^{SB}(\theta))+pY_{11}\left(\overline{A}-a^{SB}(\theta),\theta\right)+\upsilon\frac{F(\theta)}{f(\theta)}pY_{112}\left(\overline{A}-a^{SB}(\theta),\theta\right)} \tag{23}$$

where $\omega = 1/(1+\lambda)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]$ and $\upsilon = \lambda/1+\lambda$.

Our model is general and given that no assumptions have been introduced for the sign of the third derivatives $Y_{122}(a(\theta),\theta)$, $Y_{112}(a(\theta),\theta)$ we can just say that the monotonicity constraint may or may not hold. Providing that it does then $\left\{\left[a^{SB}(\theta), T^{SB}(\theta)\right]; \underline{\theta} \leq \theta \leq \overline{\theta}\right\}$ is the optimal solution and it is separating in that all types choose the contract intended for them. In this case the optimal extent of conservation in second best must satisfy the following relation

$$Y_1\left(\overline{A}-a(\theta),\theta\right) = \frac{1}{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}\left[c+\frac{B'(a(\theta))}{(1+\lambda)}\right]+ \tag{24}$$
$$-\frac{\lambda}{(1+\lambda)}Y_{12}\left(\overline{A}-a(\theta),\theta\right)\frac{F(\theta)}{f(\theta)}$$

Considering the restrictions imposed on $Y\left(\overline{A}-a(\theta),\theta\right)$ and comparing the first-best optimal allocation rule in (9) and the second best one in (24) it follows that

$$a^{FB}(\theta) \geq a^{SB}(\theta)\,\forall\theta\in\Theta=\left[\underline{\theta},\overline{\theta}\right] \tag{25}$$

Proposition 5 *Under symmetric information, the extent of conserved land is never less than that under asymmetric information.*

This distortion is due to the presence of the factor

$$\frac{\lambda}{(1+\lambda)}Y_{12}\left(\overline{A}-a(\theta),\theta\right)\frac{F(\theta)}{f(\theta)}$$

This term represents the effect of the information rent that must be paid to landowners in order to give them appropriate incentives to truthfully report their type. Note that there is no distortion only for the landowners who own the lowest type land (since $F(\underline{\theta})=0$). Decreasing the surface of land conserved by higher land type holders $\left(a^{SB\prime}(\theta)\right)$ and the compensation paid $\left(T'(\theta)\leq 0\right)$ to higher land type holders the optimal scheme proposed reduces the information rents that must paid to the lower land type holders.

Proposition 6 *If $\lambda = 0$ then the optimal CP is first best.*

First-best conservation can be attained under asymmetric information only in the case where the social cost for raising funds to pay ecosystem services is null.

Finally if the monotonicity constraint does not hold[15] then $\left[a^{SB}(\theta), T^{SB}(\theta)\right]$ is not the solution to the GA problem. The solution (see appendix A.8), which involves bunching types on the whole support or on some intervals can be derived using the Pontryagin principle (Guesnerie and Laffont , 1984; Laffont and Martimort, 2002). When it is not possible to separate the types, the GA must consider that the CP may be costly in that higher type compensation may be paid to each landowner and less conservation than expected may finally be undertaken.

3.2 Transfers

When the perverse incentive constraint is not binding and the monotonicity constraint holds the transfers can be computed simply substituting $a^{SB}\left(\overline{\theta}\right)$ and $a^{SB}(\theta)$ into (18). If the perverse incentive constraint is binding, the compensation structure changes. As proved in the appendix (A.6) the monotonicity constraint holds and the contract schedule is separating and all landowners who conserve $\widehat{a}(\theta)$ within the contract receive the same transfer ($T'(\theta) = 0$). In particular, if $\overline{\theta}$-type landowners conserve $\widehat{a}\left(\overline{\theta}\right)$ then all the landowners in the interval $\left[\theta_1, \overline{\theta}\right]$ where $a(\theta) = \widehat{a}(\theta)$, will not receive any compensation. Instead if $a(\theta) = \widehat{a}(\theta)$ is undertaken in $[\theta_1, \theta_2]$ and this interval is strictly included in $\left[\underline{\theta}, \overline{\theta}\right]$ then all the landowners in that interval will be paid the compensation computed for θ_2 for conserving the same extent of land they would have conserved privately. The GA is essentially paying them to correctly reveal their cost type.

However, without a constraint on the consistency of the policy, less conservation could have been induced for certain cost types and then controlling for this perverse effect of the CP at least avoids that payments are destined to convert more land (Motte et al. 2004). This could be actually the case in developing countries where landowners are normally credit constrained and can afford the conversion cost up to a certain extent of land. Under the program instead this constraint is relaxed in that

[15] That is $a^{SB\prime}(\theta) > 0$ or $a^{SB\prime}(\theta)$ changes sign on the support Θ.

conserving land is paying a certain return represented by the transfer and they may plan to convert more land.[16]

3.3 Optimal CP vs General Subsidy

As said in the introduction the PES programs are implemented as general subsidy schemes (hereafter, GS). In practice any landowner may enter the program, choose the extent of land to conserve and earn a fixed compensation $\overline{T}$ /ha/year. In principle, the GA should fix $\overline{T}$ in order to attract cheapest land which cost opportunity is low. Now, suppose that the GA plans to develop a GS conservation program in areas where $\underline{\theta} \leq \theta \leq \overline{\theta}$. A GS scheme is equivalent to offer the contract schedule $\{[\overline{a}(\theta), \overline{T} \cdot \overline{a}(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$ where $\overline{a}(\theta)$ is the surface that the landowners voluntarily decides to conserve under the program. It can be proved (see appendix A.7).

Proposition 7 *Social surplus from agricultural production and habitat conservation is greater under the optimal conservation program (CP) than under a general subsidy conservation program (GS).*

The GS contract schedule $\{[\overline{a}(\theta), \overline{T} \cdot \overline{a}(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$ belongs to the feasible set in that it satisfies the incentive rationality and compatibility constraints. But, since $\{[a^{SB}(\theta), T^{SB}(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$ is the best feasible contract schedule and it is the unique solution to the GA's maximization problem, social surplus cannot be lower under the optimal CP than under the GS.

A GA implementing the optimal CP designed needs to gather specific information regarding for example the structure of the landholder's profit function, the social benefit function, the cost of raising money, the distribution of types and with respect to the shock, the set of possible outcomes and their probability. The collection of this information could be costly and make less significant the gain in welfare that undoubtely may be attainted implementing this program. In fact, adding this cost to the information rent that must be paid to the landowners to reveal their type could more than balance this gain and justify the choice quite common in the reality of implementing general subsidy scheme.[17]

[16] In these countries land is surely cheaper than investing in technology to enhance the productivity of converted land.

[17] See Crepin (2005) and Arguedas et al. (2007).

4 Conservation program at work

Let now illustrate the characteristics of the mechanism under incentive compatibility by using an example. Assume

(i) $B(a) = \beta a - \frac{a^2}{2}$ as social benefit function,

(ii) $Y(\overline{A} - a, \theta) = \left(\overline{A} - a\right)\theta - \frac{\left(\overline{A}-a\right)^2}{2}$ as agricultural production function,

(iii) the uniform distribution of θ with $F(\theta) = \frac{\theta-\underline{\theta}}{\overline{\theta}-\underline{\theta}}$, $f(\theta) = \frac{1}{\overline{\theta}-\underline{\theta}}$ and

(iv) $\beta > a$, $\underline{\theta} > \overline{A} - a$, $\overline{\theta} \leq \overline{A} + \frac{c}{p[1-\overline{v}+q(\overline{v}-\underline{v})]}$, $k = [1 - \overline{v} + q(\overline{v} - \underline{v})]$.

Without any CP, the amount of land conserved is

$$\widehat{a}(\theta) = \overline{A} - \theta + \frac{c}{pk}$$

With CP in place, first best allocations are given by

$$\begin{aligned}
a^{FB}(\theta) &= \frac{1}{1 + (1+\lambda)\,pk}\left[\left(\left(\overline{A} - \theta\right)pk - c\right)(1+\lambda) + \beta\right] \\
T^{FB}(\theta) &= \left(\widehat{a}(\theta) - a^{FB}(\theta)\right)\left[pk\left(\overline{A} - \theta\right) - c\frac{\left(\widehat{a}(\theta) + a^{FB}(\theta)\right)}{2}\right]
\end{aligned}$$

Note that as proved the perverse incentive constraint does not bind in a first best scenario.

Now, assume that $a^{SB}(\theta) > \widehat{a}(\theta)$. The monotonicity constraint holds given that

$$a^{SB\prime}(\theta) = -\frac{pk(1+2\lambda)}{1 + pk(1+\lambda)} \leq 0$$

Second best allocations are then given by

$$a^{SB}(\theta) = \frac{1}{1 + (1+\lambda)\,pk}\left[\left(\left(\overline{A} - \theta\right)pk - c\right)(1+\lambda) + \beta - \left(\theta - \underline{\theta}\right)pk\lambda\right]$$

Comparing $a^{SB}(\theta)$ with $a^{FB}(\theta)$ one can see easily realize the impact of information asymmetry. The term representing the effect of the information rent is

$$-\left(\theta - \underline{\theta}\right)\frac{pk\lambda}{1 + (1+\lambda)\,pk}$$

The land to be conserved decreases with θ and in this manner the optimal mechanism reduce the amount of information rent that should be paid to the low type landowners to correctly reveal their type. If $\theta = \underline{\theta}$ the surface conserved is as expected not distorted. To derive the transfer function $T^{SB}(\overline{\theta})$ must be determined. Minimizing $\Pi\left(\overline{A} - a^{SB}\left(\overline{\theta}\right), \overline{\theta}\right)$ subject to (16) with respect to $T(\overline{\theta})$, it follows

$$\begin{aligned} T^{SB}(\overline{\theta}) &= \pi\left(\overline{A} - \widehat{a}\left(\overline{\theta}\right), \overline{\theta}\right) - \pi\left(\overline{A} - a^{SB}\left(\overline{\theta}\right), \overline{\theta}\right) \\ &= \left(\widehat{a}(\overline{\theta}) - a^{SB}(\overline{\theta})\right)\left[pk\left(\overline{A} - \overline{\theta}\right) - c\frac{\left(\widehat{a}(\overline{\theta}) + a^{SB}(\overline{\theta})\right)}{2}\right] \end{aligned}$$

The transfer function is then given by

$$\begin{aligned} T^{SB}(\theta) = \left(\widehat{a}(\overline{\theta}) - a^{SB}(\overline{\theta})\right)\left[pk\left(\overline{A} - \overline{\theta}\right) - c\frac{\left(\widehat{a}(\overline{\theta}) + a^{SB}(\overline{\theta})\right)}{2}\right] + \\ + \frac{pk\left(1 + 2\lambda\right)}{1 + pk\left(1 + \lambda\right)} \int_{\theta}^{\overline{\theta}} \left\{pk\left[\xi - \left(\overline{A} - a^{SB}(\xi)\right)\right] - c\right\} d\xi \end{aligned}$$

Note that $T^{SB\prime}(\theta) \leq 0$ and that the contract proposed is separating. The value of the private information is higher for the low types and this types have no incentive to reveal their true cost if an informational rent is not paid.

5 Concluding remarks

Combining agriculture and habitat protection is an appealing but extremely challenging target. The debate over this issue in the past decades has highlighted the idea that ecosystem services are valuable and that conservation is an alternative land use. This is important in order to support the implementation of PES programs in developing countries not as the way richer countries subsidize the welfare of the poorer but as a tool for promoting their development paying them for the valuable contribution they can provide conserving the habitat.

However, some potential weaknesses in the PES programs implementation must be overcome. We refer in particular to the lack of proper targeting and the use of undifferentiated transfers (World Bank, 2000; Salzman, 2005).

This paper draws using the mechanism design theoretical framework a conservation program which allows for the differentiation of the payments with respect to the opportunity cost of providing ecosystem services. The contract schedule proposed in alternative to the more common general subsidy scheme keeps into account the risk of poor crop yield which characterizes the agricultural activity in developing countries and control for the likely perverse effect that a conservation program could have once a compensation is paid, namely less conversion than that which would be observed without a conservation policy. The recognition of the incentive for the rational landowner to select, even misreporting, the best combination of conservation and agriculture leads to impose in addition to the incentive rationality also the incentive compatibility of the contract schedule that should be announced. Transfers and contract requirements are then set to reduce information rents that must be paid for collecting private information on the conservation costs and maximize social welfare. We verify comparing the two alternatives that a gain in welfare can be attained implementing our incentive compatible program. Nevertheless, when comparing the two schemes, one should also take into account the cost of the information required to implement the scheme and the rents that must be paid to induce revelation of true types. These costs could be high and the actual welfare gain may be too little to justify the adoption of the scheme we propose (Crépin, 2005; Arguedas et al., 2007).

In the light of the debate on the opportunity of implementing incentive compatible programs for conservation we believe that our attempt to contribute to the broad literature on this topic is completely justified and that our framework allows for the analysis of several aspects characterizing this issue. Two aspects that deserve more future research are an explicit modelling of the credit constraint for the landowners in the model and exploring the relationship between the probability of unfavourable crop yields and the environmental characteristics of the land to be converted. The second aspect could be developed in the standard principal - agent framework where differently from the model here presented the private information on θ enters into the problem not only affecting the land productivity but also the probability of a scarce crop yield and as a direct consequence the actual probability that a certain land type will be cleared. Finally, an interesting extension for future research in this field will be the analysis of the mechanism design issues in a dynamic continuous time frame where uncertainty in the return from agriculture and the irreversibility of the conversion process once undertaken are considered.

A Appendix

A.1 Proposition 1

The Lagrangian of the maximization problem in (8) is

$$L = B(a(\theta)) + (1+\lambda)\pi\left(\overline{A} - a(\theta), \theta\right) - \lambda\Pi\left(\overline{A} - a(\theta), \theta\right) +$$
$$+\gamma(\theta)\left(\Pi\left(\overline{A} - a(\theta), \theta\right) - \pi\left(\overline{A} - \widehat{a}(\theta), \theta\right)\right) + \phi(\theta)(a(\theta) - \widehat{a}(\theta))$$

where $\gamma(\theta)$ and $\phi(\theta)$ are the lagrangian multipliers attached to the constraints. Necessary conditions which must hold for an optimum are

$$\frac{\partial L}{\partial a(\theta)} = B'(a(\theta)) - (1+\lambda)\left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - a(\theta), \theta\right) - c\right\} + \tag{L.1}$$

$$+(-\lambda + \gamma(\theta))\frac{\partial\Pi\left(\overline{A} - a(\theta), \theta\right)}{\partial a(\theta)} + \phi(\theta) = 0$$

$$\frac{\partial L}{\partial\Pi\left(\overline{A} - a(\theta), \theta\right)} = -\lambda + \gamma(\theta) = 0 \tag{L.2}$$

$$\gamma(\theta)\left(\Pi\left(\overline{A} - a(\theta), \theta\right) - \pi\left(\overline{A} - \widehat{a}(\theta), \theta\right)\right) = 0, \quad \gamma(\theta) \geq 0 \tag{L.3}$$

$$\phi(\theta)(a(\theta) - \widehat{a}(\theta)) = 0, \quad \phi(\theta) \geq 0 \tag{L.4}$$

Under perfect information the payments are set to compensate the landowners for their actual economic loss. Hence, $\Pi\left(\overline{A} - a(\theta), \theta\right) = \pi\left(\overline{A} - \widehat{a}(\theta), \theta\right)$. It is then easy to check that $(L.3)$ holds being by $(L.2)$, $\gamma(\theta) = \lambda \geq 0$.

Now, assume $a^{FB}(\theta) > \widehat{a}(\theta)$ and $\phi(\theta) = 0$ and substitute $(L.2)$ into $(L.1)$. Rearranging it follows that

$$Y_1\left(\overline{A} - a^{FB}(\theta), \theta\right) =$$
$$\frac{1}{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]}\left[c + \frac{B'\left(a^{FB}(\theta)\right)}{(1+\lambda)}\right] > \frac{c}{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]}$$
$$= Y_1\left(\overline{A} - \widehat{a}(\theta), \theta\right)$$

and given the restrictions on the shape of $Y\left(\overline{A} - a(\theta), \theta\right)$

$$\begin{aligned} Y_1\left(\overline{A} - a^{FB}(\theta), \theta\right) &> Y_1\left(\overline{A} - \widehat{a}(\theta), \theta\right) \\ \overline{A} - a^{FB}(\theta) &< \overline{A} - \widehat{a}(\theta)\, a^{FB}(\theta) \\ a^{FB}(\theta) &> \widehat{a}(\theta) \end{aligned}$$

Our inital assumption is confirmed.

Checking instead the conjecture $a^{FB}(\theta) = \widehat{a}(\theta)$ and $\phi(\theta) \geq 0$ it is not difficult to prove that falls by contradiction in that substituting $(L.2)$ and (4) into $(L.1)$ we get

$$\phi(\theta) = -B'(\widehat{a}(\theta)) < 0$$

A.2 Proposition 2

If the contract schedule $\{[a(\theta), T(\theta)]; 0 \leq \theta \leq 1\}$ is incentive compatible the landowners maximize their program rents by revealing their true land type θ. Hence, θ must be the solution of the following maximization problem:

$$\max_{\widetilde{\theta}} \left[\Pi\left(\overline{A} - a(\widetilde{\theta}), \theta\right)\right] = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y\left(\overline{A} - a(\widetilde{\theta}), \theta\right) + \\ -c\left(\overline{A} - a(\widetilde{\theta})\right) + T(\widetilde{\theta}) \quad \text{(A.2.1)}$$

If θ is the solution then the following first and second order conditions must hold:

$$\left.\frac{\partial\left[\Pi(\overline{A} - a(\widetilde{\theta}), \theta)\right]}{\partial\widetilde{\theta}}\right|_{\widetilde{\theta}=\theta} = -\left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - a(\theta), \theta\right) - c\right\} a'(\theta) + \\ +T'(\theta) = 0 \quad \text{(A.2.2)}$$

$$\left.\frac{\partial^2\left[\Pi(\overline{A} - a(\widetilde{\theta}), \theta)\right]}{\partial\widetilde{\theta}^2}\right|_{\widetilde{\theta}=\theta} = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_{11}\left(\overline{A} - a(\theta), \theta\right) a'(\theta)^2 + \\ \text{(A.2.3)} \\ -\left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - a(\theta), \theta\right) - c\right\} a''(\theta) + T''(\theta) \leq 0$$

Condition (b) of Proposition 2 can be derived from (A.2.2). Given that in the optimal contract schedule (A.2.2) must hold for every θ, it follows that its derivative with respect to θ must be zero:

$$p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] [Y_{11}\left(\overline{A} - a(\theta), \theta\right) a'(\theta) - Y_{12}\left(\overline{A} - a(\theta), \theta\right)] a'(\theta) + \\ \text{(A.2.4)} \\ -\left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - a(\theta), \theta\right) - c\right\} a''(\theta) + T''(\theta) = 0$$

Comparing (A.2.3) and (A.2.4):

$$p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{12}\left(\overline{A}-a(\theta),\theta\right)a'\left(\theta\right)\leq 0 \tag{A.2.5}$$

Condition (a) follows considering that by assumption $Y_{12}\left(\overline{A}-a(\theta),\theta\right)>0$ and $p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]\geq 0$.

Now, we prove that conditions (a) and (b) are met only if the contract schedule is incentive compatible. For every θ and $\widetilde{\theta}\in\left[\underline{\theta},\overline{\theta}\right]$,

$$\Pi\left(\overline{A}-a(\theta),\theta\right)-\Pi(\overline{A}-a(\widetilde{\theta}),\theta)\geq\int_{\widetilde{\theta}}^{\theta}\frac{\partial\Pi(\overline{A}-a(\xi),\theta)}{\partial\xi}d\xi \tag{A.2.6}$$

where

$$\frac{\partial\Pi(\overline{A}-a(\xi),\theta)}{\partial\xi}=-\left\{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_1\left(\overline{A}-a(\xi),\theta\right)-c\right\}a'\left(\xi\right)+T'(\xi) \tag{A.2.7}$$

By condition (b) $T'\left(\xi\right))=\left\{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_1\left(\overline{A}-a\left(\xi\right),\xi\right)\ -c\right\}a'\left(\xi\right)$. Plugging it into (A.2.7)

$$\begin{aligned}\frac{\partial\Pi(\overline{A}-a(\xi),\theta)}{\partial\xi} &= -p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]\left[Y_1\left(\overline{A}-a(\xi),\theta\right)+\right. \\ &\quad \left.-Y_1\left(\overline{A}-a\left(\xi\right),\xi\right)\right]a'\left(\xi\right)\end{aligned} \tag{A.2.8}$$

If $\xi\in\left[\widetilde{\theta},\theta\right]$ with $\theta\geq\widetilde{\theta}$ then $Y_1\left(\overline{A}-a(\xi),\theta\right)-Y_1\left(\overline{A}-a\left(\xi\right),\xi\right)\geq 0$ since $Y_{12}\left(\overline{A}-a(\theta),\theta\right)\geq 0$ by assumption. If condition (a) holds ($a'\left(\theta\right)\leq 0$) then the integrand in (A.2.6) is nonnegative and $\Pi\left(\overline{A}-a\left(\theta\right),\theta\right)-\Pi(\overline{A}-a(\widetilde{\theta}),\theta)\geq 0$. By the same arguments, if $\theta\leq\widetilde{\theta}$ then the integrand in (A.2.6) is nonpositive. But considering that we are integrating backwards then it still follows $\Pi\left(\overline{A}-a\left(\theta\right),\theta\right)-\Pi(\overline{A}-a(\widetilde{\theta}),\theta)\geq 0$.

A.3 Larger total rents for the higher type

Total differentiating the program rent function in (12)

$$\frac{\partial\left[\Pi\left(\overline{A}-a\left(\theta\right),\theta\right)\right]}{\partial\theta}=-\left[p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{1}\left(\overline{A}-a(\theta),\theta\right)-c\right]a'\left(\theta\right)+ \tag{A.3.1}$$

$$+p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{2}\left(\overline{A}-a(\theta),\theta\right)+T'(\theta)$$

plugging condition (b) into (A.3.1), and considering that $Y_2\left(\overline{A}-a(\theta),\theta\right)>0$ the following relation holds

$$\frac{\partial\left[\Pi\left(\overline{A}-a\left(\theta\right),\theta\right)\right]}{\partial\theta}=p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{2}\left(\overline{A}-a(\theta),\theta\right)>0 \tag{A.3.2}$$

A.4 Proposition 3

By the envelope theorem and using (4)

$$\frac{\partial\left[\pi\left(\overline{A}-\widehat{a}\left(\theta\right),\theta\right)\right]}{\partial\theta}=-\left\{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{1}\left(\overline{A}-\widehat{a}\left(\theta\right),\theta\right)-c\right\}\widehat{a}'\left(\theta\right)+ \tag{A.4.1}$$

$$\begin{aligned}&+p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{2}\left(\overline{A}-\widehat{a}\left(\theta\right),\theta\right)\\&=p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{2}\left(\overline{A}-\widehat{a}\left(\theta\right),\theta\right)>0\end{aligned}$$

Under the CP $a(\theta)\geq\widehat{a}\left(\theta\right)$. Comparing (5) with (17) and being $Y_{12}>0$ it follows that

$$\frac{\partial\left[\pi\left(\overline{A}-\widehat{a}\left(\theta\right),\theta\right)\right]}{\partial\theta}\geq\frac{\partial\left[\pi\left(\overline{A}-a\left(\theta\right),\theta\right)\right]}{\partial\theta} \tag{A.4.2}$$

That is, $\Pi\left(\overline{A}-a\left(\theta\right),\theta\right)-\pi\left(\overline{A}-\widehat{a}\left(\theta\right),\theta\right)$ is non increasing in θ.

Hence, if $\Pi\left(\overline{A}-a\left(\overline{\theta}\right),\overline{\theta}\right)-\pi\left(\overline{A}-\widehat{a}\left(\overline{\theta}\right),\overline{\theta}\right)\geq 0$ then $\Pi\left(\overline{A}-a\left(\theta\right),\theta\right)-\pi\left(\overline{A}-\widehat{a}\left(\theta\right),\theta\right)\geq 0$ for every $\theta<\overline{\theta}$.

A.5 Proposition 4

Denote the term $[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)]$ by k and use condition (b) in proposition 2 to rearrange $T(\theta)$ as follows

$$\begin{aligned}
T(\theta) &= T(\overline{\theta}) - \int_{\theta}^{\overline{\theta}} T'(\xi)d\xi \\
&= T(\overline{\theta}) - \int_{\theta}^{\overline{\theta}} \left\{pkY_1\left(\overline{A}-a\left(\xi\right),\xi\right) \ -c\right\} a'\left(\xi\right)d\xi \\
&= T(\overline{\theta}) + \int_{\theta}^{\overline{\theta}} \frac{d\ \left\{pkY\left(\overline{A}-a\left(\xi\right),\xi\right)-c\left(\overline{A}-a\left(\xi\right)\right)\right\}}{d\xi}d\xi + \\
&- \int_{\theta}^{\overline{\theta}} pkY_2\left(\overline{A}-a(\xi),\xi\right)d\xi \\
&= T(\overline{\theta}) + \ \left\{pkY\left(\overline{A}-a\left(\overline{\theta}\right),\overline{\theta}\right)-c\left(\overline{A}-a\left(\overline{\theta}\right)\right)\right\} + \\
&- \left\{pkY\left(\overline{A}-a\left(\theta\right),\theta\right)-c\left(\overline{A}-a\left(\theta\right)\right)\right\} - k\int_{\theta}^{\overline{\theta}} pY_2\left(\overline{A}-a(\xi),\xi\right)d\xi \\
&= \Pi\left(\overline{A}-a\left(\overline{\theta}\right),\overline{\theta}\right) - \left\{pkY\left(\overline{A}-a\left(\theta\right),\theta\right)-c\left(\overline{A}-a\left(\theta\right)\right)\right\} + \\
&- k\int_{\theta}^{\overline{\theta}} pY_2\left(\overline{A}-a(\xi),\xi\right)d\xi
\end{aligned} \tag{A.5.1}$$

Substituting (A.5.1) into (15)

$$\begin{aligned}
E_{\theta}\left[W\right] = &\int_{\underline{\theta}}^{\overline{\theta}} \{B\left(a\left(\theta\right)\right) + \left(1+\lambda\right)pkY\left(\overline{A}-a\left(\theta\right),\theta\right) - c\left(\overline{A}-a\left(\theta\right)\right)\}f\left(\theta\right)d\theta + \\
&+\lambda k\int_{\underline{\theta}}^{\overline{\theta}}\int_{\theta}^{\overline{\theta}} pY_2\left(\overline{A}-a(\xi),\xi\right)d\xi f\left(\theta\right)d\theta - \lambda\Pi\left(\overline{A}-a\left(\overline{\theta}\right),\overline{\theta}\right)
\end{aligned}$$

Integrating by parts the last term of $E_{\theta}\left[W\right]$

$$\begin{aligned}
E_{\theta}\left[W\right] = &\int_{\underline{\theta}}^{\overline{\theta}} \{B\left(a\left(\theta\right)\right) + \left(1+\lambda\right)pkY\left(\overline{A}-a\left(\theta\right),\theta\right) - c\left(\overline{A}-a\left(\theta\right)\right)\}f\left(\theta\right)d\theta + \\
&+\lambda k\int_{\underline{\theta}}^{\overline{\theta}} pY_2\left(\overline{A}-a(\theta),\theta\right)F\left(\theta\right)d\theta - \lambda\Pi\left(\overline{A}-a\left(\overline{\theta}\right),\overline{\theta}\right)
\end{aligned}$$

$$= \int_{\underline{\theta}}^{\overline{\theta}} \{B(a(\theta)) + (1+\lambda)\left[pkY\left(\overline{A} - a(\theta), \theta\right) - c\left(\overline{A} - a(\theta)\right)\right] +$$

$$+ \lambda kpY_2\left(\overline{A} - a(\theta), \theta\right)\frac{F(\theta)}{f(\theta)}\} f(\theta)\, d\theta - \lambda\Pi\left(\overline{A} - a\left(\overline{\theta}\right), \overline{\theta}\right)$$

$$= (1+\lambda)\, k \int_{\underline{\theta}}^{\overline{\theta}} \Phi\left[a(\theta), \theta\right] f(\theta)\, d\theta - \lambda\Pi\left(\overline{A} - a\left(\overline{\theta}\right), \overline{\theta}\right) \qquad \text{(A.5.2)}$$

To maximize (A.5.2) or (17) is equivalent.

A.6 Binding perverse incentive constraint

By condition (a) in Proposition 2 $a^{SB\prime}(\theta) \leq 0$. Set $a^{SB}(\theta) = \widehat{a}(\theta)$. Totally differentiate (4)

$$-p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]\left[Y_{11}\left(\overline{A} - \widehat{a}(\theta), \theta\right)\widehat{a}'(\theta) - Y_{12}\left(\overline{A} - \widehat{a}(\theta), \theta\right)\right] = 0$$

Solving for $\widehat{a}'(\theta)$, it follows

$$\widehat{a}'(\theta) = \frac{Y_{12}\left(\overline{A} - \widehat{a}(\theta), \theta\right)}{Y_{11}\left(\overline{A} - \widehat{a}(\theta), \theta\right)} < 0 \qquad \text{(A.6.1)}$$

This means that the monotonicity constraint is always satisfied on the interval $[\theta_1, \theta_2]$.

Substituting $\widehat{a}(\theta)$ into condition (b) of Proposition 2

$$T'(\theta) = \left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - \widehat{a}(\theta), \theta\right) \; - c\right\}\widehat{a}'(\theta) = 0$$

If type $\overline{\theta}$ landowners conserve $\widehat{a}\left(\overline{\theta}\right)$ then minimizing $T^{SB}(\overline{\theta})$ such that (16) holds involves

$$T^{SB}(\overline{\theta}) = 0 \qquad \text{(A.6.2)}$$

Moreover, if $\theta_2 = \overline{\theta}$ being $T'(\theta) = 0$ it follows that all the landowners undertaking $a(\theta) = \widehat{a}(\theta)$ in the interval $\left[\theta_1, \overline{\theta}\right]$ will not get any compensation.

A.7 Feasibility of a GS program

Under the GS program $T(\theta) = \overline{T} \cdot a(\theta)$ and the landowner chooses to conserve $\overline{a}(\theta)$. It follows that

$$\pi\left(\overline{A} - \overline{a}(\theta), \theta\right) + \overline{T} \cdot \overline{a}(\theta) \geq \pi\left(\overline{A} - \widehat{a}(\theta), \theta\right) \tag{A.7.1}$$

and this meet the incentive rationality requirement.

If conditions (a) and (b) of Proposition 2 are met then the GS program is incentive compatible. The landowner's rent is given by

$$\begin{aligned} \Pi\left(\overline{A} - \overline{a}(\theta), \theta\right) &= \pi\left(\overline{A} - \overline{a}(\theta), \theta\right) + \overline{T} \cdot \overline{a}(\theta) \qquad \text{(A.7.2)} \\ &= p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y\left(\overline{A} - \overline{a}(\theta), \theta\right) - c\left(\overline{A} - \overline{a}(\theta)\right) + \overline{T} \cdot \overline{a}(\theta) \end{aligned}$$

Maximizing (A.7.2) with respect to $\overline{a}(\theta)$ the landowner defines the surface to be conserved. From the foc

$$Y_1\left(\overline{A} - \overline{a}(\theta), \theta\right) = \frac{c + \overline{T}}{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]} \tag{A.7.3}$$

Differentiating totally (A.7.3) and solving for $\overline{a}'(\theta)$

$$\overline{a}'(\theta) = \frac{Y_{12}\left(\overline{A} - \overline{a}(\theta), \theta\right)}{Y_{11}\left(\overline{A} - \overline{a}(\theta), \theta\right)} < 0 \tag{A.7.4}$$

and condition (a) is satisfied.

If $T(\theta) = \overline{T} \cdot \overline{a}(\theta)$ then $T'(\theta) = \overline{T} \cdot \overline{a}'(\theta)$. Substituting $T'(\theta)$ into condition (b)

$$\overline{T} \cdot \overline{a}'(\theta) = \left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - \overline{a}(\theta), \theta\right) - c\right\} \overline{a}'(\theta) \tag{A.7.5}$$

The relation is satisfied considering that rearranging (A.7.3)

$$\overline{T} = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_1\left(\overline{A} - \overline{a}(\theta), \theta\right) - c \tag{A.7.6}$$

A.8 Bunching types

Bunching arises if the monotonicity constraint does not hold. We solve then (17) following Guesnerie and Laffont (1984). Restate the problem as follows

$$
\begin{aligned}
& \max_{a(\theta),\gamma(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} \Phi\left[a(\theta),\theta\right] f(\theta)\, d\theta \\
& s.t. \\
\gamma(\theta) &= a'(\theta) \qquad \text{(C1)} \\
\gamma(\theta) &\leq 0 \qquad \text{(C2)}
\end{aligned}
$$

where $a(\theta)$ and $\gamma(\theta)$ are respectively the state and the control variable. Attaching the multiplier $\mu(\theta)$ to (C2) the Hamiltonian for the problem is given by

$$H(a,\gamma,\mu,\theta) = \Phi\left[a(\theta),\theta\right] f(\theta) - \mu\gamma \qquad \text{(A.8.1)}$$

From the Pontryagin principle:

$$
\begin{aligned}
\mu'(\theta) &= -\frac{\partial H}{\partial a} = -\frac{\partial \Phi\left[a(\theta),\theta\right]}{\partial a(\theta)} f(\theta) \qquad \text{(A.8.2)} \\
\mu(\theta)\gamma(\theta) &= 0,\ \mu(\theta) \geq 0 \qquad \text{(A.8.3)}
\end{aligned}
$$

Suppose the existence of an interval where the monotonicity constraint (C2) is not binding. On this interval, $\mu(\theta) = 0$ everywhere and $\mu'(\theta) = 0$. In this case the optimal solution is $a^{SB}(\theta)$.

Consider now an interval $[\theta_m, \theta_M] \subseteq \left[\underline{\theta}, \overline{\theta}\right]$ where $a'(\theta) = 0$. It follows that $\gamma(\theta) = 0$ and $a(\theta)$ is constant and equal to a constant h. Observing that on the left and on the right of $[\theta_m, \theta_M]$ (C2) is not binding by continuity of $\mu(\theta)$ it follows that $\mu(\theta_m) = \mu(\theta_M) = 0$. Integrate (A.8.2) on $[\theta_m, \theta_M]$:

$$\int_{\theta_m}^{\theta_M} \frac{\partial \Phi\left[k,\theta\right]}{\partial a(\theta)} f(\theta)\, d\theta = 0$$

or

$$
\begin{aligned}
& \int_{\theta_m}^{\theta_M} \left\{ pY_1(h,\theta) f(\theta) + \frac{\lambda}{(1+\lambda)} pY_{12}(h,\theta) F(\theta) \right\} d\theta \qquad \text{(A.8.4)} \\
&= \int_{\theta_m}^{\theta_M} \frac{1}{1-\overline{v}+q(\overline{v}-\underline{v})} \left[\frac{B'\left(\overline{A}-h\right)}{(1+\lambda)} + c \right] f(\theta)\, d\theta
\end{aligned}
$$

One could compute the unknown θ_m, θ_M and h, setting the values which satisfies (A.8.4) and $h = a^{SB}(\theta_m) = a^{SB}(\theta_M)$.

To summarize if $a'(\theta) > 0$ on the whole support, Θ, then the agency will bunch types. All landowners will retire the same amount of land, $a(\theta) = h$, and receive the same transfer $T(\overline{\theta})$. Since landowner's profit is costly for the agency then the optimal transfer, $T^{SB}(\overline{\theta})$, is such that $\Pi\left(\overline{A} - h, \overline{\theta}\right) = \pi\left(\overline{A} - h, \overline{\theta}\right)$ .There is no alternative for the GA if she wants to keep feasible the program. If $a'(\theta) > 0$ on some intervals of Θ but $a'(\theta) \leq 0$ on others then it is not possible to separate some θ. The solution will pool some segments of the interval Θ with $a'(\theta) \leq 0$ and others with $a'(\theta) > 0$. On these segments the landowners retire the same amount of land and get the same transfer.

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