Mechanism design for biodiversity conservation

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Abstract

This paper deals with the design of voluntary incentive contracts to conserve biodiversity in the context of forested areas in developing countries. The aim of the environmental agency implementing the conservation program is to induce the landowners to set aside a part of their land from agriculture conversion, compensating them for the resulting profit loss. A principal-agent model under adverse selection is developed to analyse the effect of information asymmetry arising from the lack of information of the environmental agency about the type of land.

1 INTRODUCTION

In the last decades the conservation of biodiversity has been increasingly emphasized in the design of conservation programs (thereafter, CPs) run by national and international environmental agencies. The target of these policies is to prevent too vast land conversion to agricultural regime which produces an irreversible loss of biodiversity.The implementation of incentive measures for the conservation of biodiversity on private lands has been mainly based on the definition of conservation contracts (OECD 1999).

One problem with using this instrument is that landowners typically have more information about their land characteristics than does the conservation agency implementing a conservation program. This information asymmetry implies that often the program does not attain a first best outcome. When this is the case, second-best outcomes can be obtained by applying mechanism design theory under asymmetric information (Mirrles 1971; Groves, 1973; Dasgupta, Hammond and Maskin, 1979; Baron and Myerson, 1982; Guesnerie and Laffont, 1984). This direction in research has recently produced some contributions which differently deal with the information asymmetry problem in the conservation contracts setting (Smith and Shogren, 2002; Wu and Babcock, 1996; Smith, 1995; Goeschl and Lin, 2004).

This paper deals with CPs in the context of forested areas in developing countries and specifically focuses on the design of voluntary incentive contracts to conserve biodiversity. The contract I investigate is between an environmental agency (thereafter, EA) and a landowner: in the EA's aim, this contract should induce the landowner to set aside a part of her land from agriculture conversion, compensating her for the resulting profit loss.

In so doing, the present paper differs from previous contributions in two respects. First, the level of conservation pursued by the EA through the incentive contract is not fixed ex-ante, but results from the social welfare maximization. Second, we consider the agricultural production as a risky activity and we allow for the possibility of a shock that negatively affects the landowner's crop yield.

Thus, it turns out that in our contribution the EA's social welfare function maximization weights the social benefit from conservation along with the expected agricultural profit, and the cost of raising money for funding the CP's transfers.

Moreover, the source of asymmetric information I investigate reflects the set of environmental characteristics which affects the landowner's agricultural productivity. The CP is designed to guarantee voluntary participation and truthful revelation of land type.

The second-best CP finally proposed solves the conversion/conservation social dilemma allocating land according to its agricultural productivity.

The structure of the paper is the following: in section 2, the landowner and EA's preferences are presented, and the private allocation - when no CP is at work - is defined. In section 3, we investigate the resulting full information allocation when the CP is implemented: the first best is the benchmark case, and we compare it with the level of conservation obtained in the no CP case. In section 4 we investigate the second best case, derive and discuss its properties, and compare its results with the benchmark. Section 5 concludes.

2 THE BASIC MODEL

I consider the problem of a EA who wants to preserve some critical habitat for conserving biodiversity on private land. I assume each landowner is endowed with $\overline{A}$ units of land and that each plot is still in its pristine natural state. Each landowner's plot is homogenous but not necessarily of the same quality/type of the one owned by another landowner. I assume also that the EA, wants to propose a voluntary scheme for biodiversity conservation that compensates for the private property that is not converted to agriculture. In the voluntary scheme, each landowner voluntarily conserves $A = \overline{A} - a$ units of his plot and benefit of a transfer. The funding of the transfers is raised by taxation. In the model I assume that the agency and the landowners are risk-neutral agents.

2.1 Landowner and Environmental Agency preferences

Each landowner's plot is characterized by a set of environmental characteristics that affect the agricultural productivity, i.e. soil quality, soil erosion, water, etc. To simplify, I use a scale index θ that represents the environmental characteristics. This parameter varies among landowners and defines the type of the agent. The agricultural productivity of the plot is positively related with θ. I assume that θ is unobservable to the EA, but 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 $f(\theta)$. I assume also that $f(\theta)$ is strictly positive on the support Θ and verifies the regularity conditions such that $\partial\left[F(\theta)/f(\theta)\right]/\partial\theta \geq 0$[1].

Crop yield to the landowner are represented by $(1-v)\,Y(a,\theta)$ where a is the surface cultivated on the plot of type θ and v is a random shock due to the presence of persistent weeds or pests which could negatively affect the yield. It is assumed that v belongs to the set $V = \{\underline{v}, \overline{v}\}$ where $0 \leq \underline{v} < \overline{v} \leq 1$ and it is $\underline{v}$ or $\overline{v}$ with respective probability q and $1-q$. Given that, the expected crop yield is:

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

I assume $Y_a > 0$, $Y_{aa} \leq 0$, $Y_\theta > 0$ and $Y_{a\theta} > 0$ (where $Y_x = \partial Y/\,\partial x, Y_{xz} = \partial^2 Y/\,\partial x \partial z$). The agricultural production function is increasing and concave in units of land converted and it is also increasing in types. Marginal product is increasing in types.

Without any CP, the expected rents to each landowner's a units of land of type θ are represented by:

$$\pi(a,\theta) = p\left[1 - \overline{v} + q\,(\overline{v} - \underline{v})\right] Y(a,\theta) - ca \qquad (2)$$

where p is the price of the product and c is the private cost for converting a unit of land (it may be related to the cost of clearing the new plot and settle it).

I assume that, even without any CP, not all the available land is converted and cultivated $\left(a < \overline{A}\right)$ and then in the maximization problem the land constraint is non binding. If a CP is absent every landowner maximizes her expected rents with respect to the converted surface, a, not taking into account the land constraint:

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

From the first order condition (thereafter, foc):

$$\left[1 - \overline{v} + q\,(\overline{v} - \underline{v})\right] Y_a(a,\theta) = \frac{c}{p} \qquad (3)$$

Equalising her expected marginal land productivity with her private cost of converting, the landowner optimally defines the amount of land that she wants to cultivate. I denote that amount by $\widehat{a}(\theta)$. Substituting $\widehat{a}(\theta)$ into the expected profit function I define the optimal level of expected profit:

[1] This sufficient condition is satisfied by most parametric single-peak densities (Bagnoli and Bergstrom, 1989).

$$\widehat{\pi}(a,\theta) = p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y\left(\widehat{a}(\theta),\theta\right) - c\widehat{a}(\theta) \tag{4}$$

via envelope theorem and using (3):

$$\begin{aligned}\frac{\partial\left[\widehat{\pi}(a,\theta)\right]}{\partial\theta} &= \left\{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_a\left(\widehat{a}(\theta),\theta\right)-c\right\}\widehat{a}'(\theta) + \\ &\quad + p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_\theta\left(\widehat{a}(\theta),\theta\right) \\ &= p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_\theta\left(\widehat{a}(\theta),\theta\right) \end{aligned} \tag{5}$$

Rearranging (3):

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

and considering assumptions on $Y(a,\theta)$ it follows that the surface converted increases as the private cost of converting c/p decreases and/or the expectations on the crop yield, $[1-(1-q)\overline{v}-q\underline{v}]$, increase. Expectations depends on the importance of the shocks, and their likelihood.

If a CP is proposed then the agency announces and commits itself to a voluntary contract schedule $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$, where $a(\theta)$ is the amount of land cultivated and $T(\theta)$ is the transfer from the agency if the landowner reports land type θ. Symmetrically I could consider as object of the contract the units of land conserved $\overline{A}-a(\theta)$. Thus, the EA proposes a transfer to compensate the landowner of the economic loss she experiences by not converting land to agriculture. In this case expected program rents are:

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

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

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

where $\lambda > 0$ [2] is the marginal deadweight loss from (distortionary) taxation and $B\left(\overline{A}-a(\theta)\right)$ is the social benefit deriving from preserving of $\overline{A}-a(\theta)$ units of land. I assume that $B\left(\overline{A}-a(\theta)\right)$ is increasing and strictly concave in its argument.

3 FIRST BEST ALLOCATIONS

I model the CP as a mechanism design problem. As standard in this literature I first define the properties of the complete information allocation in order to refer to the first best as a benchmark. In the first best situation the information

[2] One may also interpret this variable as a Lagrange multiplier attached to the government budget constraint, reflecting the political cost of raising taxes.

is complete and the agency knows each landowner's type. Hence, the agency's problem can be formally stated as:

$$\begin{aligned} \max_{a(\theta),T(\theta)} W &= B\left(\overline{A} - a(\theta)\right) - (1+\lambda)\, T(\theta) + \Pi(a(\theta), \theta) \\ & \quad s.t. \\ \Pi(a(\theta), \theta) &\geq \widehat{\pi}(a, \theta) \quad for\ all\ \theta \in \left[\underline{\theta}, \overline{\theta}\right] \end{aligned} \tag{8}$$

The constraint ensures voluntary participation to the contract and in the literature is generally defined as the individual rationality constraint (thereafter, IRC). This constraint guarantees that the landowners will be at least as well off participating in the program as not participating. In our setting the landowner's participation constraints are type-dependent as the revenues she would earn not partecipating to the CP are related to the productivity of her own plot. The lagrangian is:

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

I used the relation (6) to rearrange W and I attached the IRC associating the Lagrange multiplier $\gamma(\theta)$. Necessary conditions for an optimum under complete information include:

$$\frac{\partial L}{\partial a(\theta)} = -B'\left(\overline{A} - a(\theta)\right) + (1+\lambda)\left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_a(a(\theta), \theta) - c\right\} = 0 \tag{$KT.1$}$$

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

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

From $(KT.2)$, $\gamma(\theta) > 0$ and this implies that $(KT.3)$ hold only if the IRC binds always. From $(KT.1)$ and $(KT.2)$ I derive then:

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

The agency maximizes its objective function with respect to $a(\theta)$ when accepting the contract the landowner equalizes her expected marginal productivity of land with her private cost of clearing land plus the social opportunity cost (social benefit from conserving) due to the choice of converting land. The surface converted still depends as shown above on the private clearing cost and on the expectations in terms of crop yield. The risk in the production could have huge consequences in landowner decisions and it has to be considered when the necessity of implementing a CP is considered and when such program is designed.

Taking into account also the social consequences of her action the landowner should reduce the amount of land converted. In (9) the marginal social benefit from conserving is adjusted by $(1+\lambda)$ and this reflects the existence of a trade off between the cost of raising money taxing people and the benefit that society will have conserving. In fact as λ increases the surface cultivated is larger and less conservation is performed.

I denote the optimal solution by $a^{FB}(\theta)$. To ensure that the biodiversity conservation target is hit I must prove now that level of conservation within the contract is at least equal to the level allocated without contract.

Proof. From (3) I derive that when $a(\theta) = \widehat{a}(\theta)$:
$Y_a(\widehat{a}(\theta), \theta) = \frac{c}{p[1-\overline{v}+q(\overline{v}-\underline{v})]}$
Instead from (9) when $a(\theta) = a^{FB}(\theta)$:
$Y_a\left(a^{FB}(\theta), \theta\right) = \frac{1}{p[1-\overline{v}+q(\overline{v}-\underline{v})]}\left[c + \frac{B'\left(\overline{A}-a^{FB}(\theta)\right)}{(1+\lambda)}\right]$

Given the properties I assumed for $Y(a(\theta), \theta)$ and $B\left(\overline{A} - a(\theta)\right)$ the following relations hold:
$Y_a\left(a^{FB}(\theta), \theta\right) > Y_a(\widehat{a}(\theta), \theta)$ and
$a^{FB}(\theta) < \widehat{a}(\theta)$
$\overline{A} - a^{FB}(\theta) > \overline{A} - \widehat{a}(\theta)$ ■

It follows:

Proposition 1 *With full information, the surface allocated to agriculture within the program is less than without the program for every* $\theta \in \left[\underline{\theta}, \overline{\theta}\right]$.

4 SECOND BEST ALLOCATIONS

The EA announces and commits itself to a voluntary contract $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$. The landowners have more information about their type than does the EA who only knows the distribution of θ, $F(\theta)$.The context is mainly characterized by the presence of an adverse selection problem but also moral hazard issues could arise. By assuming that the agency is able to perfectly enforce the contract once it has been accepted I focus only on the first problem. After observing the contract schedule proposed, each landowner chooses whether to accept or not to accept the contract and in this sense the participation is voluntary. If she accepts, she must reveal her type, $\widehat{\theta}$, reporting it to the agency and she must allocate $a(\widehat{\theta})$ to the agricultural regime. The informational advantage of the landowner over the agency could generate a positive information rent, which could give to the landowner the incentive to mimic her type. Hence, the agency needs to design a contract schedule such that for each landowner agent is optimal to report their land type truthfully. In addition to be voluntary the CP mechanism must also satisfy a truth-telling condition (Dasgupta, Hammond and Maskin, 1979). To take into account also this requirement I must add a constraint to the agency's maximization problem. In the literature, this constraint is defined as the self-selection or incentive compatibility constraint (thereafter, ICC).

If type-θ landowners choose the schedule intended for type-$\widetilde{\theta}$ landowners, $[a(\widetilde{\theta}), T(\widetilde{\theta})]$, their expected program rents are:

$$\Pi(a(\widetilde{\theta}), \theta) = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y\left(a(\widetilde{\theta}), \theta\right) - ca(\widetilde{\theta}) + T(\widetilde{\theta}) \tag{10}$$

Instead, if they choose the schedule intended for them, $[a(\theta), T(\theta)]$,their program rents would be:

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

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

$$\Pi\left(a\left(\theta\right), \theta\right) \geq \Pi(a(\widetilde{\theta}), \theta), \quad for\ all\ \theta\ and\ \widetilde{\theta} \in \left[\underline{\theta}, \overline{\theta}\right] \tag{12}$$

In this way the type-θ landowners will prefer $[a(\theta), T(\theta)]$ to all other options available in the menu. To ensure voluntary participation as in the first best case the contract schedule has to satisfy the IRC:

$$\Pi\left(a\left(\theta\right), \theta\right) \geq \widehat{\pi}\left(a, \theta\right) \tag{13}$$

It follows:

Proposition 2 *A CP is feasible if it satisfies both the incentive compatibility constraint and the individual rationality constraint.*

The agency's target is then to find the feasible program that maximizes its objective function. Its problem can now be formally stated as:

$$\begin{aligned}
\max_{a(\theta), T(\theta)} E_{\theta}\left[W\right] &= \int_{\underline{\theta}}^{\overline{\theta}} [B\left(\overline{A} - a\left(\theta\right)\right) + \pi\left(a(\theta), \theta\right) - \lambda T\left(\theta\right)] f\left(\theta\right) d\theta \\
& \quad s.t. \\
\Pi\left(a\left(\theta\right), \theta\right) &\geq \widehat{\pi}\left(a, \theta\right) \\
\Pi\left(a\left(\theta\right), \theta\right) &\geq \Pi(a(\widetilde{\theta}), \theta), \quad for\ all\ \theta\ and\ \widetilde{\theta} \in \left[\underline{\theta}, \overline{\theta}\right]
\end{aligned} \tag{14}$$

4.1 Analysis of the mechanism

To describe the properties of the mechanism, I must state and prove three lemmas.

Lemma 1 *A contract schedule* $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \overline{\theta}\}$ *is incentive compatible if and only if*

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

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

Proof. A contract schedule is incentive compatible only if the landowners maximize their program rents by revealing their true land type. Hence if

$\{[a(\theta), T(\theta)]; 0 \leq \theta \leq 1\}$ is incentive compatible then θ must be the solution of the following maximization problem:

$$\max_{\widetilde{\theta}} \left[\Pi\left(a(\widetilde{\theta}), \theta\right)\right] = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y\left(a(\widetilde{\theta}), \theta\right) - ca(\widetilde{\theta}) + T(\widetilde{\theta}) \tag{15}$$

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

$$\begin{aligned} \left.\frac{\partial\left[\Pi(a(\widetilde{\theta}), \theta)\right]}{\partial\widetilde{\theta}}\right|_{\widetilde{\theta}=\theta} &= \left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_a\left(a(\theta), \theta\right) - c\right\} a'(\theta) + \\ +T'(\theta) &= 0 \end{aligned} \tag{16}$$

$$\begin{aligned} \left.\frac{\partial^2\left[\Pi(a(\widetilde{\theta}), \theta)\right]}{\partial\widetilde{\theta}^2}\right|_{\widetilde{\theta}=\theta} &= p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_{aa}\left(a(\theta), \theta\right) a'(\theta)^2 + \\ &+ \left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_a\left(a(\theta), \theta\right) - c\right\} a''(\theta) + T''(\theta) \leq 0 \end{aligned} \tag{17}$$

From (16) I derive condition (b) of Lemma 1. The EA must impose in her contract schedule that (16) holds for every θ; if it holds also its derivative with respect to θ must be zero:

$$\begin{aligned} &p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]\left[Y_{aa}\left(a(\theta), \theta\right) a'(\theta)^2 + Y_{a\theta}\left(a(\theta), \theta\right) a'(\theta)\right] + \\ &+ \left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_a\left(a(\theta), \theta\right) - c\right\} a''(\theta) + T''(\theta) = 0 \end{aligned} \tag{18}$$

Comparing (17) and (18) I obtain:

$$p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_{a\theta}\left(a(\theta), \theta\right) a'(\theta) \geq 0 \tag{19}$$

Since $Y_{a\theta}\left(a(\theta), \theta\right) > 0$ by assumption and $p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] \geq 0$ then condition (a) follows.

Now I must show that if the contract schedule menu satisfies (a) and (b) then it is incentive compatible. For every θ and $\widetilde{\theta} \in \left[\underline{\theta}, \overline{\theta}\right]$,

$$\Pi\left(a(\theta), \theta\right) - \Pi(a(\widetilde{\theta}), \theta) \geq \int_{\widetilde{\theta}}^{\theta} \frac{\partial\Pi(a(\xi), \theta)}{\partial\xi} d\xi \tag{20}$$

where

$$\frac{\partial\Pi(a(\xi), \theta)}{\partial\xi} = \left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_a\left(a(\xi), \theta\right) - c\right\} a'(\xi) + T'(\xi) \tag{21}$$

From condition (b), $T'(\xi) = -\left\{p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_a\left(a(\xi), \xi\right) - c\right\} a'(\xi)$, and substituting it into (21) I obtain:

$$\frac{\partial\Pi(a(\xi), \theta)}{\partial\xi} = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]\left[Y_a\left(a(\xi), \theta\right) - Y_a\left(a(\xi), \xi\right)\right] a'(\xi) \tag{22}$$

If $\xi \in \left[\widetilde{\theta}, \theta\right]$ with $\theta \geq \widetilde{\theta}$ then $Y_a\left(a(\xi), \theta\right) - Y_a\left(a\left(\xi\right), \xi\right) \geq 0$ because I assumed $Y_a\left(a(\theta), \theta\right)$ is increasing in θ by assumption. Condition (a) states $a'\left(\theta\right) \geq 0$ and then with $\theta \geq \widetilde{\theta}$ the integrand in (20) is nonnegative and $\Pi\left(a\left(\theta\right), \theta\right) - \Pi(a(\widetilde{\theta}), \theta) \geq 0$.

If $\theta \leq \widetilde{\theta}$ then $Y_a\left(a(\xi), \theta\right) - Y_a\left(a\left(\xi\right), \xi\right) \leq 0$ and considering $a'\left(\theta\right) \geq 0$ this implies that the integrand in (20) is nonpositive. But also in this case the integral in (20) is nonnegative because the integration has to be done backwards and then it still follows $\Pi\left(a\left(\theta\right), \theta\right) - \Pi(a(\widetilde{\theta}), \theta) \geq 0$. Hence, when conditions (a) and (b) hold, the contract schedule is incentive compatible. ■

Conditions (a) and (b) represents the local incentive constraints, which guarantee that the landowner does not want to lie locally. In the second part of the proof I have shown that the landowner does not want to lie globally either and that local incentive constraints imply the global incentive constraints. The ICCs in (12) reduce then to a differential equation (b) and to a monotonicity constraint (b) that completely characterize the truthful direct revelation mechanism.

If condition (a) holds the incentive compatible program is in practice asking to allocate less units of land to agriculture if land productivity is low or symmetrically more conservation should be done on low quality land. Without program the landowners would choose the land allocation according to the rule $pY_a\left(a, \theta\right) = c/\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]$ while within the program considering that $pY_a\left(a\left(\theta\right), \theta\right) \geq c/\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right]$ the land converted to agriculture is reduced. Hence, condition (b) would imply that $T'\left(\theta\right) \leq 0$. Agency should then reduce transfers as land quality increases under a incentive compatible program because if not there would be incentive for every landowner to report that her land is of the top quality in order to allocate more land to agriculture and be entitled to a larger transfer. The landowners who report higher and higher land quality face then the trade off between increase in converted and cultivated land with the decrease in transfers. To summarize then the contract schedule should be such that the land conversion function is nondecreasing in land quality while the transfer function is nonincreasing in land quality.

Even if the transfer decreases with the land quality, the landowners with more productive land must receive larger program rents otherwise there would be incentive for them to report a lower quality because they may anyway earn a larger total rent than the landowners who owns low quality land. I verify if the contract schedule allows for it studying the total derivative of the program rent function in equation (11):

$$\begin{aligned} \frac{\partial\left[\Pi\left(a\left(\theta\right), \theta\right)\right]}{\partial\theta} &= \left[p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_a\left(a(\theta), \theta\right) - c\right] a'\left(\theta\right) + \\ &\quad + p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_\theta\left(a(\theta), \theta\right) + T'(\theta) \end{aligned} \tag{23}$$

Substituting condition (b) into (23) and since $Y_\theta\left(a(\theta), \theta\right) > 0$ I obtain:

$$\frac{\partial\left[\Pi\left(a\left(\theta\right), \theta\right)\right]}{\partial\theta} = p\left[1 - \overline{v} + q\left(\overline{v} - \underline{v}\right)\right] Y_\theta\left(a(\theta), \theta\right) > 0 \tag{24}$$

Actually, the landowners with more productive land have larger expected program rents.

Lemma 2 *For any incentive compatible program, the individual rationality constraint is satisfied when*

$$\Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right)-\widehat{\pi}\left(a,\overline{\theta}\right)\geq 0 \tag{25}$$

Proof. Without program I have defined the rent for type-θ landowners by equation (4) and its total derivative with respect to θ by equation (5). Within the program there is more conservation for every θ and then $a(\theta)\leq\widehat{a}\left(\theta\right).$

Comparing (5) with (24) and knowing that $Y_{a\theta}\left(a(\theta),\theta\right)>0$ relation (26) follows :

$$\partial\left[\widehat{\pi}\left(a,\theta\right)\right]/\partial\theta\geq\partial\left[\Pi\left(a\left(\theta\right),\theta\right)\right]/\partial\theta \tag{26}$$

That is, $\Pi\left(a\left(\theta\right),\theta\right)-\widehat{\pi}\left(a,\theta\right)$ is nonincreasing in θ. Hence, if $\Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right)-\widehat{\pi}\left(a,\overline{\theta}\right)\geq 0$ then $\Pi\left(a\left(\theta\right),\theta\right)-\widehat{\pi}\left(a,\theta\right)$ is nonnegative for every $\theta<\overline{\theta}$ and the IRC is always satisfied. ■

Thus, given the ICC , the IRC will hold when the owners of top quality land are not worse off under the CP. As long as they will accept the contract also all the other landowners will accept.

Proposition 3 *A CP is feasible if it satisfies conditions (a) and (b) of lemma 1 and equation (25) in lemma 2.*

Lemma 3 *The EA's problem in equation (14) can be restated as follows:*

a)

$$\max_{a(\theta)}\int_{\underline{\theta}}^{\overline{\theta}}\Phi\left[a\left(\theta\right),\theta\right]f\left(\theta\right)d\theta \tag{27}$$
$$s.t.\quad a'\left(\theta\right)\geq 0$$

where

$$\begin{aligned}\Phi\left[a\left(\theta\right),\theta\right] &= \frac{B\left(A-a\left(\theta\right)\right)}{\left(1+\lambda\right)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}+pY\left(a\left(\theta\right),\theta\right)-\frac{ca\left(\theta\right)}{\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}+\\ &\quad+\frac{\lambda}{\left(1+\lambda\right)}pY_{\theta}\left(a(\theta),\theta\right)\frac{F\left(\theta\right)}{f\left(\theta\right)}\end{aligned}$$

b) Given the optimal allocation schedule, $a^{SB}\left(\theta\right)$, derived from (27), the optimal transfer schedule, $T^{SB}(\theta)$, is defined by

$$T^{SB}(\theta)=T^{SB}(\overline{\theta})+\int_{\theta}^{\overline{\theta}}\left[p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]Y_{a}\left(a\left(\xi\right),\xi\right)\ -c\right]a^{SB\,\prime}(\xi)d\xi \tag{28}$$

where $T^{SB}(\overline{\theta})$ is chosen to minimize the transfer such that (25) holds.

Proof. Using condition (b) of lemma 1 I can rearrange $T(\theta)$ as

$$\begin{aligned} T(\theta) &= T(\overline{\theta}) - \int_{\theta}^{\overline{\theta}} T'(\xi)d\xi \qquad (29) \\ &= T(\overline{\theta}) + \int_{\theta}^{\overline{\theta}} \{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] Y_a\left(a\left(\xi\right),\xi\right) \ -c\} \, a'\left(\xi\right) d\xi \\ &= T(\overline{\theta}) + \int_{\theta}^{\overline{\theta}} \frac{d\ \{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] Y\left(a\left(\xi\right),\xi\right) - ca\left(\xi\right)\}}{d\xi} d\xi + \\ &\quad - \int_{\theta}^{\overline{\theta}} p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] Y_{\theta}\left(a(\xi),\xi\right) d\xi \\ &= T(\overline{\theta}) + \ \left\{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] Y\left(a\left(\overline{\theta}\right),\overline{\theta}\right) - ca\left(\overline{\theta}\right)\right\} + \\ &\quad - \{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] Y\left(a\left(\theta\right),\theta\right) - ca\left(\theta\right)\} + \\ &\quad - \left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] \int_{\theta}^{\overline{\theta}} pY_{\theta}\left(a(\xi),\xi\right) d\xi \\ &= \Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right) - \{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] Y\left(a\left(\theta\right),\theta\right) - ca\left(\theta\right)\} + \\ &\quad - \left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] \int_{\theta}^{\overline{\theta}} pY_{\theta}\left(a(\xi),\xi\right) d\xi \end{aligned}$$

Substituting (29) into (14) I can write

$$\begin{aligned} E_{\theta}\left[W\right] &= \int_{\underline{\theta}}^{\overline{\theta}} \{B\left(A-a\left(\theta\right)\right) + (1+\lambda)\left[p\left(1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right) Y\left(a\left(\theta\right),\theta\right) - ca\left(\theta\right)\right]\} f\left(\theta\right) d\theta + \\ &\quad + \lambda\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] \int_{\underline{\theta}}^{\overline{\theta}} \int_{\theta}^{\overline{\theta}} pY_{\theta}\left(a(\xi),\xi\right) d\xi f\left(\theta\right) d\theta - \lambda\Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right) \qquad (30) \end{aligned}$$

Integrating by parts the last term of $E_{\theta}\left[W\right]$ I can rewrite (30) as

$$\begin{aligned} E_{\theta}\left[W\right] &= \int_{\underline{\theta}}^{\overline{\theta}} \{B\left(A-a\left(\theta\right)\right) + (1+\lambda)\left[p\left(1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right) Y\left(a\left(\theta\right),\theta\right) - ca\left(\theta\right)\right]\} f\left(\theta\right) d\theta + \\ &\quad + \lambda\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] \int_{\underline{\theta}}^{\overline{\theta}} pY_{\theta}\left(a(\theta),\theta\right) F\left(\theta\right) d\theta - \lambda\Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right) \\ &= \int_{\underline{\theta}}^{\overline{\theta}} \{B\left(A-a\left(\theta\right)\right) + (1+\lambda)\left[p\left(1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right) Y\left(a\left(\theta\right),\theta\right) - ca\left(\theta\right)\right] + \\ &\quad + \lambda\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] pY_{\theta}\left(a(\theta),\theta\right) \frac{F\left(\theta\right)}{f\left(\theta\right)}\} f\left(\theta\right) d\theta - \lambda\Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right) \\ &= (1+\lambda)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right] \int_{\underline{\theta}}^{\overline{\theta}} \Phi\left[a\left(\theta\right),\theta\right] f\left(\theta\right) d\theta - \lambda\Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right) \qquad (31) \end{aligned}$$

■

To maximize (31) is or to solve the maximization problem in (27) is equivalent considering that $(1+\lambda)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]$ does not depend on θ.

4.2 Properties of the optimal contract schedule

With lemma 1 I have illustrated the properties of an incentive compatible contract schedule, lemma 2 has been used to rearrange the IRC and finally presenting lemma 3 I have proposed a formulation of the agency's problem that allows to derive the properties of the optimal program.

I solve the problem in (31) in two steps. At first, I determine $a^{SB}(\theta)$ solving the maximization problem in (27). Second step is to determine the $T(\overline{\theta})$ that minimizes $\Pi\left(a\left(\overline{\theta}\right),\overline{\theta}\right)$ subject to (25). The optimal transfer schedule is then easily derived substituting $a^{SB}(\theta)$ and $T^{SB}(\overline{\theta})$ into (28).

To be the solution $a^{SB}(\theta)$ must satisfy the following condition:

$$\begin{aligned}\frac{\partial\Phi\left[a(\theta),\theta\right]}{\partial a(\theta)} &= -\frac{B'\left(A-a^{SB}(\theta)\right)}{(1+\lambda)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}+pY_a\left(a^{SB}(\theta),\theta\right)+ \\ &\quad -\frac{c}{\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}+\frac{\lambda}{(1+\lambda)}pY_{a\theta}\left(a^{SB}(\theta),\theta\right)\frac{F(\theta)}{f(\theta)}=0\end{aligned} \tag{32}$$

Now, according to the constraint in (27) $a^{*\prime}(\theta)$ must be nondecreasing. To verify it I totally differentiate (32):

$$\begin{aligned}0 &= \left[\omega B''\left(A-a^{SB}(\theta)\right)+pY_{aa}\left(a^{SB}(\theta),\theta\right)+\upsilon\frac{F(\theta)}{f(\theta)}pY_{aa\theta}\left(a^{SB}(\theta),\theta\right)\right]a^{SB\prime}(\theta)(\theta)+ \\ &\quad +pY_{a\theta}\left(a^{SB}(\theta),\theta\right)+\upsilon\frac{F(\theta)}{f(\theta)}pY_{a\theta\theta}\left(a^{SB}(\theta),\theta\right)+\upsilon pY_{a\theta}\left(a^{SB}(\theta),\theta\right)\frac{\partial\left[F(\theta)/f(\theta)\right]}{\partial\theta}\end{aligned}$$

where $\omega = 1/(1+\lambda)\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]$ and $\upsilon = \lambda/1+\lambda$. Solving for $a^{SB\prime}(\theta)$:

$$a^{SB\prime}(\theta) = -\frac{pY_{a\theta}\left(a^{SB}(\theta),\theta\right)+\upsilon\frac{F(\theta)}{f(\theta)}pY_{a\theta\theta}\left(a^{SB}(\theta),\theta\right)+\upsilon pY_{a\theta}\left(a^{SB}(\theta),\theta\right)\frac{\partial[F(\theta)/f(\theta)]}{\partial\theta}}{\omega B''\left(A-a^{SB}(\theta)\right)+pY_{aa}\left(a^{SB}(\theta),\theta\right)+\upsilon\frac{F(\theta)}{f(\theta)}pY_{aa\theta}\left(a^{SB}(\theta),\theta\right)} \tag{33}$$

Nothing has been assumed about the sign of $Y_{a\theta\theta}\left(a(\theta),\theta\right)$, $Y_{aa\theta}\left(a(\theta),\theta\right)$ and then it is not clear if the monotonicity constraint holds. If it does then $a^{SB}(\theta)$ is the second best solution and in this case all types choose different allocations and there is no bunching problem in the optimal contract. If $a^{SB\prime}(\theta)<0$ or $a^{SB\prime}(\theta)$ changes sign on the support Θ then $a^{SB}(\theta)$ is not the solution. The solution, which involves bunching respectively on the whole support or on some intervals can be derived using the Pontryagin principle (Guesnerie and Laffont , 1984; Laffont and Martimort, 2002). In what follows I assume that the monotonicity constraint holds and in the appendix I show the case where the constraint does not hold.

Now, I compare the first-best cultivated surface with the second-best one. If $a(\theta) = a^{FB}(\theta)$ then via relation (9) I get

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

Instead if $a\left(\theta\right)=a^{SB}\left(\theta\right)$ using (32)

$$\begin{aligned} Y_a\left(a\left(\theta\right),\theta\right) &= \frac{1}{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}\left[c+\frac{B'\left(\overline{A}-a\left(\theta\right)\right)}{\left(1+\lambda\right)}\right]+ \\ &\quad -\frac{\lambda}{\left(1+\lambda\right)}Y_{a\theta}\left(a(\theta),\theta\right)\frac{F\left(\theta\right)}{f\left(\theta\right)} \end{aligned} \tag{34}$$

Given the assumptions on $Y\left(a\left(\theta\right),\theta\right)$ the following relation holds :

$$a^{FB}\left(\theta\right)\leq a^{SB}\left(\theta\right)\forall\theta\in\Theta=\left[\underline{\theta},\overline{\theta}\right] \tag{35}$$

In second best the optimal policy allows to the landowners to cultivate more than allowed with full information. The distortion is due to the presence of this factor:

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

This factor represents the information rent that must be paid in terms of amount of land that can be converted. Only paying them a rent they will truthfully report their type. I note that there is no distortion only for the landowners who owns the lowest type land (since $F\left(\underline{\theta}\right)=0$).

5 CONCLUSIONS

Conservation programs may be a valid instrument when Environmental Agencies want to modify the weak structure of incentives for conservation on private land. However, the implementation of such programs meets some difficulties.

At first, not only the way environmental characteristics affects the agricultural productivity should be taken into account but also how those characteristics could affect the benefits from conservation.

Second, the problems related to the incomplete information could have important consequences on the program outcome because information asymmetry may be not only precontractual. Moreover, moral hazard and adverse selection can emerge even together (Goeschl and Lin, 2004).

Third, the funding of conservation programs, the fact that it is mainly raised by taxation has to be carefully considered.

And finally, the importance that enforcement costs may have when it is difficult to check if the contract has been fulfilled.

I have dealt with only two of the problems illustrated: the information asymmetry on the land type and the welfare losses related to the distortionary taxation.

With respect to the first I have shown in this paper how to design a mechanism that allows for voluntary participation and truthful revelation and I have discussed the mechanism properties. The need of paying an information rent to give to the landowners the incentive for truth telling has been illustrated and justified.

The existence of a trade-off between marginal loss due to distortionary taxation and the marginal benefit from conservation has been correctly addressed and discussed.

A APPENDIX

I study in this appendix the bunching problem that could arise if the monotonicity constraint does not hold. I can restate the problem in (27) as follows:

$$\max_{a(\theta),\gamma(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} \Phi\left[a\left(\theta\right),\theta\right] f\left(\theta\right) d\theta$$

$$a'\left(\theta\right) = \gamma\left(\theta\right) \tag{C1}$$

$$\gamma\left(\theta\right) \geq 0 \tag{C2}$$

where I define $a\left(\theta\right)$ as the state variable and $\gamma\left(\theta\right) = a'\left(\theta\right)$ as the control variable. I attach the multiplier $\mu\left(\theta\right)$ to (C2). The Hamiltonian is then:

$$H(a,\gamma,\mu,\theta) = \Phi\left[a\left(\theta\right),\theta\right] f\left(\theta\right) + \mu\gamma \tag{A1}$$

From the Pontryagin principle:

$$\mu'\left(\theta\right) = -\frac{\partial H}{\partial a} = -\frac{\partial \Phi\left[a\left(\theta\right),\theta\right]}{\partial a\left(\theta\right)} f\left(\theta\right) \tag{A2}$$

$$\mu\left(\theta\right)\gamma\left(\theta\right) = 0,\ \ \mu\left(\theta\right) \geq 0 \tag{A3}$$

Consider now an interval where the monotonicity constraint (C2) is not binding. Then, $\mu\left(\theta\right) = 0$ and therefore $\mu'\left(\theta\right) = 0$ on this interval. Given that and using (A2) the optimal solution on this interval is then the second best solution, $a^{SB}\left(\theta\right)$.

Instead on an interval $[\theta_1, \theta_2]$ where the monotonicity constraint is binding, $\gamma\left(\theta\right) = 0$ and $a\left(\theta\right)$ is constant. I denote by k this value. Considering that (C2) is not binding to the left and to the right of $[\theta_1, \theta_2]$ and because of the continuity of the multiplier, $\mu\left(\theta\right)$, then I have $\mu\left(\theta_1\right) = \mu\left(\theta_2\right) = 0$.Integrating (A2) on $[\theta_1, \theta_2]$ I get:

$$\int_{\theta_1}^{\theta_2} \frac{\partial \Phi\left[k,\theta\right]}{\partial a\left(\theta\right)} f\left(\theta\right) d\theta = 0 \tag{A4}$$

or

$$
\begin{aligned}
&\int_{\theta_1}^{\theta_2}\left\{pY_a(k,\theta)\,f(\theta)+\frac{\lambda}{(1+\lambda)}pY_{a\theta}(k,\theta)\,F(\theta)\right\}d\theta \qquad \text{(A5)}\\
=\;&\int_{\theta_1}^{\theta_2}\frac{1}{1-\overline{v}+q\left(\overline{v}-\underline{v}\right)}\left[\frac{B'(A-k)}{(1+\lambda)}+c\right]f(\theta)\,d\theta
\end{aligned}
$$

Then integrating by parts on RHS and rearranging on LHS:

$$
\begin{aligned}
&\frac{\lambda\left[Y_a(k,\theta_2)\,F(\theta_2)-Y_a(k,\theta_1)\,F(\theta_1)\right]+\int_{\theta_1}^{\theta_2}Y_a(k,\theta)\,f(\theta)\,d\theta}{\left[B'(A-k)+c\,(1+\lambda)\right]} \qquad \text{(A6)}\\
=\;&\frac{\left[F(\theta_2)-F(\theta_1)\right]}{p\left[1-\overline{v}+q\left(\overline{v}-\underline{v}\right)\right]}
\end{aligned}
$$

To compute the unknown θ_1, θ_2 and k, A6 and other two equations, $k = a^{SB}(\theta_1) = a^{SB}(\theta_2)$, are used.

To summarize if $a'(\theta) \leq 0$ on the support $\Theta = \left[\underline{\theta}, \overline{\theta}\right]$ then the agency will bunch landowner types, with all landowners retiring the same amount of land, $a(\theta) = k$, and receiving 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 $\Pi\left(a\left(\overline{\theta}\right), \overline{\theta}\right) = \widehat{\pi}\left(a, \overline{\theta}\right)$. The agency has no alternative because if not the IRC would not hold and the program would be not feasible (lemma 2 and proposition 3). If $a'(\theta) \geq 0$ in some intervals of Θ but $a'(\theta) \leq 0$ in others then it is not possible to separate some θ. All segments in Θ with $a'(\theta) \leq 0$ and some with $a'(\theta) \geq 0$ will be pooled and the related landowners will retire the same amount of land, and will get the same transfer.

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