

Mechanism Design for Biodiversity Conservation in Developing Countries

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Abstract

In this paper the theory and practical limits of a voluntary incentive program for the conservation of biodiversity are presented. The design of conservation contracts in the context of still forested areas in developing countries is considered. The aim of the governmental 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. The optimal contract scheme needs to deal with information asymmetry on the opportunity cost of conservation and reduces the information rents due to the landholder incentive to misreport her "type". I show how information asymmetry can seriously impact on the optimal mechanism design and may lead to contracts by which types cannot be separated and/or landholders may receive some payments even if they are conserving the same extent of land they would have conserved without contract.

KEYWORDS: biodiversity conservation; asymmetric information; mechanism design.

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1 INTRODUCTION

Ecosystems provide valuable services. These services are usually neither marketable nor explicitly protected by the law. In recent years, an increasing number

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of initiatives¹ aiming to develop markets for these services have been implemented around the world. Most of them are dependent on government intervention and some are created by entirely private ventures (Salzman, 2005).

An approach, which has become increasingly popular is to provide payments for the provision of ecosystem services (Ferraro, 2001; Ferraro and Kiss, 2002; Pagiola et al., 2002). A well known example of this type of intervention is the PSA (Pagos por Servicios Ambientales) program that Costa Rica launched in 1997. The PSA allows the government² to enter into binding contracts with landowners for the provision of four services: mitigation of greenhouse gases, water quantity and quality (urban, rural and hydroelectric services), biodiversity conservation, and aesthetic beauty for ecotourism (FONAFIFO, 2000; Pagiola et al., 2002; Salzman, 2005).

The target for most of the land managed under the PSA program has been the conservation of biodiversity. By the middle of 2000, roughly 200,000 hectares of forest were being managed for biodiversity conservation in exchange for payments (Salzman, 2005). This important result is due primarily to the available resources and numbers of willing buyers³.

Through these contracts⁴, the landholders agree not to convert part of the existing natural forests to agriculture and are compensated for the environmental services that they provide.

The PSA program resembles a general subsidy scheme in that it allows any landholder in the country, to participate and to be paid the same amount. In principle, the payment⁵ should be at least equal to the landholders' opportunity cost and no higher than the value of the benefit provided. Though this approach has the virtue of simplicity, it fails to differentiate payments with respect to different levels of benefit and different opportunity cost⁶ basically ensuring the suboptimal targeting of public funds. The value of the benefit provided by biodiversity conservation is extremely difficult to assess. In contrast, the landholder's opportunity cost can be estimated more easily and then at least with respect to this parameter it could be possible to improve the design of the PSA program.

The aim of this paper is the design of voluntary incentive contracts for the conservation of biodiversity. The scheme will be designed to differentiate the payments with respect to the land opportunity cost. In the implementation

¹For details and examples, see <http://epp.gsu.edu/pferraro/special/special.htm>.

²A body called FONAFIFO (Fondo Nacional de Financiamiento Forestal) has been created to administer the program (e.g., to negotiate the agreements, monitor compliance, administer payments, etc.).

³Under the Ecomarkets Project, the World Bank, with a \$32.6 million loan, and the Global Environment Facility (GEF), with a \$8 million grant, have provided the funding for paying biodiversity conservation (World Bank, 2000).

⁴Most contracts cover a five years period, though they can be renewed indefinitely if there is mutual agreement.

⁵This payment is currently fixed at US\$45/ha/year and it has been quite attractive considering that a number of applications for conservation management were not considered in the program because of inadequate funding (Pagiola et al., 2004).

⁶There have been no studies up to date examining the likelihood that the land managed under the PSA would have been cleared for logging in the absence of the program.

of such an incentive scheme, information issue may arise. Landholders know their property and the opportunity cost of managing it for biodiversity conservation better than the governmental agency (hereinafter, GA). This information asymmetry could make it difficult to attain a first-best outcome. If this is the case then second-best outcomes can be obtained by applying mechanism design theory under asymmetric information⁷ (Mirrles 1971; Groves, 1973; Dasgupta, Hammond and Maskin, 1979; Baron and Myerson, 1982; Guesnerie and Laffont, 1984).

A principal-agent model is used to deal with information asymmetry 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. The Conservation Program (hereinafter, CP) is then designed to guarantee voluntary participation and truthful revelation of land opportunity cost. The second-best solution proposed solves the conversion/conservation social dilemma and allocates land according to its agricultural productivity.

In doing so, the present paper differs from previous contributions in three respects. First, the level of conservation pursued by the GA through the CP is not fixed ex-ante, but results from the social welfare maximization. The regulator's social welfare function includes the benefit from conservation along with the agricultural profit, and the cost of raising money for funding the CP payments. Second, a constraint on the surface conserved in second best is introduced in order to control for the effectiveness of the policy. Its purpose is to avoid that landholders conserve less than what they would have done without a contract. Finally, the agricultural production is modelled as a risky activity allowing for the possibility of an exogenous shock that negatively affects the landholder's crop yield.

The structure of the paper is the following: in section 2, the landholder and regulator's preferences are presented; the private allocation with no CP and the first best allocation with CP in place are presented and discussed. In section 3, the second best outcome is derived and I discuss its properties. Using the first best allocation as a benchmark, a comparison with second-best outcome is also provided. The main result obtained is that the second best program is the optimal or best feasible contract schedule that the GA could design. In fact, it has been shown that social surplus under PSA program cannot be higher than under the optimal second best scheme. The PSA program is then compared with the optimal CP and its suboptimality is proved showing that social surplus under the optimal CP is greater than under the PSA program. Section 4 proposes a parametric example of the optimal CP at work. Section 5 concludes.

⁷This direction of research has recently produced some contributions that 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).

2 THE BASIC MODEL

I assume that each landholder is endowed with \bar{A} units of land and that each plot is in its pristine natural state. Each landholder's plot is of the same size but not necessarily of the same quality/type of the one owned by another landholder. The GA wants to preserve some critical habitat for conserving biodiversity on this private land and proposes a voluntary contracts scheme. According to the scheme, each landholder is paid to allocate a units of her plot to conservation. I further assume that the agency and the landholders are risk-neutral agents and that the funding of the transfers is raised by taxation.

2.1 Landholder and Government Agency preferences

Each landholder's plot is characterized by a set of environmental characteristics, such as soil quality, soil erosion and water. For the sake of simplicity, I use the scale index θ to represent these characteristics. This parameter varies among landholders and defines their type. The agricultural productivity of the plot is affected by the characteristics of the plot and I assume that it is positively related to θ . The index θ is unobservable to the GA, but it is common knowledge that it is drawn from the interval $\Theta = [\underline{\theta}, \bar{\theta}]$ 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 conditions⁸ such that $\frac{\partial[F(\theta)/f(\theta)]}{\partial\theta} \geq 0$.

Crop yield to the landholder is represented by

$$(1 - v)Y(\bar{A} - a, \theta) \quad (1)$$

where $\bar{A} - a$ is the surface cultivated, θ is the land type and v is a random shock, such as the presence of persistent weeds or pests, which may negatively affect the yield. I assume that v belongs to the set $V = \{\underline{v}, \bar{v}\}$ where $0 \leq \underline{v} < \bar{v} \leq 1$ and it is equal to \underline{v} or \bar{v} with probability q and $1 - q$ respectively. Therefore, the expected crop yield is

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

Assume $Y_1 > 0$, $Y_{11} < 0$, $Y_2 > 0$ and $Y_{12} > 0$ ($Y_1 = \partial Y / \partial(\bar{A} - a)$, $Y_2 = \partial Y / \partial\theta$, $Y_{11} = \partial^2 Y / \partial(\bar{A} - a)^2$, $Y_{12} = \partial^2 Y / \partial(\bar{A} - a)\partial\theta$). That is, the production is increasing and concave in units of land converted and increasing in θ . The marginal product, Y_1 , is also increasing in land type.

In the absence of a CP, the expected profits to each landholder's $\bar{A} - a$ units of land are represented by

⁸This sufficient condition is satisfied by most parametric single-peak densities (Bagnoli and Bergstrom, 1989).

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

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.

Assume also that the landholder do not convert all the available land even without signing a conservation contract ($a > 0$). Hence, the constraint on land availability is non binding⁹.

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

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

Rearranging the first order condition (hereinafter, foc)

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

it follows that

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

That is, equalising her expected marginal land productivity with her private cost of converting, the landholder optimally defines the surface to be cultivated. Given the assumptions on $Y(\bar{A} - a, \theta)$ then the surface converted increases as the private cost of converting, c/p , decreases and/or the expectations on the crop yield, $[1 - \bar{v} + q(\bar{v} - \underline{v})]$, increase. Expectations depend on the importance of the exogenous shock and its likelihood.

Denote the optimal surface by $\bar{A} - \hat{a}(\theta)$ and substituting it into the expected profit function one may define the optimal level of expected profit as

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

If a CP is proposed then the agency announces and commits itself to a voluntary contract schedule $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \bar{\theta}\}$, where $a(\theta)$ is the surface to be conserved and $T(\theta)$ is the transfer paid to a landholder reporting land type θ . If the landholder accepts the contract then her expected program rents are

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

The agency's objective¹⁰ is the maximization of the social surplus, W , with respect to the pair $[a(\theta), T(\theta)]$. Social surplus is defined as

⁹Indeed, in Latin America, landholders are often credit-constrained and can afford the cost of the conversion just up to a certain extent of land. Another aspect to be considered is how far the land is with respect to the markets.

¹⁰Although the agency faces n agents, it can view the multi-agent problem as a single-agent problem repeated n times.

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

where λ is the shadow cost of public funds¹¹. The function $B(a(\theta))$ represents the social benefit derived from the preservation of $a(\theta)$ units of land. I assume that $B(a(\theta))$ is increasing and strictly concave in its argument and that $\lambda > 0$.

2.2 Full Information Allocation

I model the CP as a mechanism design problem. As standard in the literature I first define the properties of the complete information allocation in order to refer to this case as a benchmark. In the first best situation the information is complete and the agency knows each landholder's type. Hence, the agency's problem can be formally stated as:

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

The first constraint is the individual rationality constraint (hereinafter, IRC) and it ensures voluntary participation to the program. This constraint guarantees that the landholders are at least as well off accepting the contract as not accepting it. The landholder's participation constraint is type-dependent as the return she would earn not participating to the program is related to the productivity of her own plot. The second constraint is introduced to guarantee that the landholders conserve at least the same surface of land that they would have conserved without contract. Not introducing this constraint, the CP, relaxing landholder's financial constraints through the transfer, could end up providing incentives to convert more land. Hereinafter, I will refer to this constraint as the perverse incentive constraint (PIC).

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

See appendix A.1 for the proof.

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

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

The agency maximizes its objective function with respect to $a(\theta)$ when accepting the contract the landholder equalizes her expected land marginal productivity with her private cost of clearing land plus the negative externality generated

¹¹It can be interpreted also as a Lagrange multiplier attached to the government budget constraint. It could reflect the political cost of raising taxes or the marginal deadweight loss from (distortionary) taxation.

by converting land. 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 landholder decisions and it has to be considered when a CP is designed. Internalizing the social cost of her action the landholder reduces the surface 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 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

$$T^{FB}(\theta) = \pi(\bar{A} - \hat{a}(\theta), \theta) - \pi(\bar{A} - a^{FB}(\theta), \theta) \quad (10)$$

3 MECHANISMS UNDER INCENTIVE COMPATIBILITY

The GA commits itself to a voluntary contract $\{[a(\theta), T(\theta)]; \underline{\theta} \leq \theta \leq \bar{\theta}\}$. The landholders have more information about their type than the GA. The regulator only knows the distribution of θ , $F(\theta)$. The context is characterized by the presence of an adverse selection problem but also moral hazard issues could arise (Goeschl and Lin, 2004). Assume that the agency perfectly enforces the contract once accepted and focuses only on the first problem. The participation is voluntary and after observing the contract schedule proposed, each landholder chooses whether to accept or not the contract. If she accepts, she reveals her type, θ , to the agency and has to conserve $a(\theta)$.

The landholder's informational advantage over the agency may generate a positive information rent, which could give her the incentive to mimic her type. Hence, the agency must design a contract schedule such that for each landholder it is optimal to report the land type truthfully¹². In the literature, this constraint is known as the self-selection or incentive compatibility constraint (hereinafter, ICC).

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

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

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

¹²In addition to be voluntary the CP mechanism must satisfy a truth-telling condition (Dasgupta, Hammond and Maskin, 1979). Another constraint is then introduced into the agency's maximization problem.

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

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

$$\Pi(\bar{A} - a(\theta), \theta) \geq \Pi(\bar{A} - a(\tilde{\theta}), \theta), \quad \text{for all } \theta \text{ and } \tilde{\theta} \in [\underline{\theta}, \bar{\theta}] \quad (13)$$

That is, type- θ landholders always prefer $[a(\theta), T(\theta)]$ to all other options available in the contracts menu.

To ensure voluntary participation the contract schedule should also satisfy the IRC:

$$\Pi(\bar{A} - a(\theta), \theta) \geq \pi(\bar{A} - \hat{a}(\theta), \theta) \quad (14)$$

It follows:

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

The agency's problem can now be formally stated as

$$\begin{aligned} \max_{a(\theta), T(\theta)} E_{\theta}[W] &= \int_{\underline{\theta}}^{\bar{\theta}} [B(a(\theta)) + \pi(\bar{A} - a(\theta), \theta) - \lambda T(\theta)] f(\theta) d\theta \\ &\quad \text{s.t.} \\ \Pi(\bar{A} - a(\theta), \theta) &\geq \pi(\bar{A} - \hat{a}(\theta), \theta) \\ \Pi(\bar{A} - a(\theta), \theta) &\geq \Pi(\bar{A} - a(\tilde{\theta}), \theta) \\ a(\theta) &\geq \hat{a}(\theta) \quad \text{for all } \theta \in [\underline{\theta}, \bar{\theta}] \end{aligned} \quad (15)$$

3.1 Analysis of the mechanism

To characterize the optimal mechanism for CP, let me state three lemmas (see the appendix for the proofs). Lemma 1 and 2 rearrange respectively the ICC and the IRC and lemma 3 proposes a reformulation of the agency's problem.

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

$$\begin{aligned} (a) \quad &a'(\theta) \leq 0 \\ (b) \quad &T'(\theta) = \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - a(\theta), \theta) - c\} a'(\theta) \end{aligned}$$

Conditions (a) and (b) represents the local incentive constraints, which guarantee that the landholder does not lie locally. In the appendix I show that the landholder does not want to lie globally either and that local incentive constraints imply also global incentive constraints. Hence, the ICC in (13) reduces to a differential equation (a) and to a monotonicity constraint (b), which completely characterize a truthful direct revelation mechanism.

If condition (a) holds the incentive compatible program is, in practice, asking to conserve more units of land where land productivity is low.

Without CP the landholders choose the land allocation according to the rule $Y_1(\bar{A} - a, \theta) = \frac{c}{p[1-\bar{v}+q(\bar{v}-\underline{v})]}$ while within CP they decide according to $Y_1(\bar{A} - a(\theta), \theta) \geq \frac{c}{p[1-\bar{v}+q(\bar{v}-\underline{v})]}$. Condition (b) would then imply $T'(\theta) \leq 0$. Under an incentive compatible program the GA should reduce total transfers as land quality increases because otherwise low type landholders would have an incentive to report a high type in order to allocate more land to agriculture and be entitled to a larger transfer. The landholders who want to mimic high land quality face then the trade off between increase in converted land and decrease in transfers.

Even if the total transfer decreases with the land quality, the high type landholders must end up earning larger total rents otherwise they would have incentive to report a lower type knowing that even cultivating less their land is more productive than reported (see appendix A.3).

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

$$\Pi(\bar{A} - a(\bar{\theta}), \bar{\theta}) - \pi(\bar{A} - \hat{a}(\bar{\theta}), \bar{\theta}) \geq 0 \quad (16)$$

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 accept also all the other landholders will accept the contract.

Proposition 3 *A CP is feasible if it satisfies conditions (a) and (b) of lemma 1 and condition (16) in lemma 2.*

Lemma 3 *The GA's problem in equation (15) can be restated as follows:*

a)

$$\begin{aligned} & \max_{a(\theta)} \int_{\underline{\theta}}^{\bar{\theta}} \Phi[a(\theta), \theta] f(\theta) d\theta \\ & \text{s.t.} \\ & a'(\theta) \leq 0 \\ & a(\theta) \geq \hat{a}(\theta) \end{aligned} \quad (17)$$

where

$$\begin{aligned} \Phi[a(\theta), \theta] = & \frac{B(a(\theta))}{(1+\lambda)[1-\bar{v}+q(\bar{v}-\underline{v})]} + pY(\bar{A} - a(\theta), \theta) + \\ & - \frac{c(\bar{A} - a(\theta))}{[1-\bar{v}+q(\bar{v}-\underline{v})]} + \frac{\lambda}{(1+\lambda)} pY_2(\bar{A} - a(\theta), \theta) \frac{F(\theta)}{f(\theta)} \end{aligned}$$

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

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

where $T^{SB}(\bar{\theta})$ is chosen to minimize the transfer such that (16) holds.

3.2 Properties of the optimal contract schedule

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

3.2.1 Perverse Incentive Constraint

Ignore for the moment the monotonicity constraint and focus on the impact of the PIC. The problem is then equivalent to the maximization of the following Lagrangian:

$$L = \int_{\underline{\theta}}^{\bar{\theta}} \Phi[a(\theta), \theta] f(\theta) d\theta + \phi(\theta) (a(\theta) - \hat{a}(\theta))$$

Necessary conditions for an optimum under incomplete information include:

$$\begin{aligned} \frac{\partial L}{\partial a(\theta)} &= \frac{B'(a(\theta))}{(1+\lambda)[1-\bar{v}+q(\bar{v}-\underline{v})]} - pY_1(\bar{A} - a(\theta), \theta) + \frac{c}{[1-\bar{v}+q(\bar{v}-\underline{v})]} + \\ &\quad - \frac{\lambda}{(1+\lambda)} pY_{12}(\bar{A} - a(\theta), \theta) \frac{F(\theta)}{f(\theta)} + \phi(\theta) = 0 \end{aligned} \quad (KT.1)$$

$$\phi(\theta) (a(\theta) - \hat{a}(\theta)) = 0, \quad \phi(\theta) \geq 0 \quad (KT.2)$$

Consider an interval $[\theta_1, \theta_2] \subseteq [\underline{\theta}, \bar{\theta}]$ with $\theta_1 < \theta_2$. Now, suppose $a(\theta) = \hat{a}(\theta)$ and $\phi(\theta) > 0$. Substituting (5) into (KT.1)

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

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

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

This result contradicts the assumption and then at least for $\theta = \underline{\theta}$, $\phi(\theta)$ must be null and the constraint is not binding. Hence, landholders with the lowest type land conserve more than they would have done without contract. It follows that $\underline{\theta} < \theta_1$. To analyze what happens in the rest of the interval one could study the derivative of $\phi(\theta)$

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

Without any information on the shape of the functions the derivative can take both signs and then the PIC can be binding for certain θ on the interval assumed.

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

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

That is, if the marginal cost of information (LHS) is greater than the marginal benefit from conservation (RHS) then the surface conserved within the contract is equal to that without contract. If the inequality does not hold then the contract allows for additional level of conservation with respect to the case in which there is no contract. In this case $a(\theta) > \widehat{a}(\theta)$ and $\phi(\theta) = 0$ and the optimal $a(\theta)$ must satisfy the following condition:

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

3.2.2 Monotonicity Constraint

An optimal second best program requires $a^{SB'}(\theta) \leq 0$. First, consider $a^{SB}(\theta) = \widehat{a}(\theta)$. In this case it can be proved that on the interval $[\theta_1, \theta_2]$ the monotonicity constraint is always satisfied (see the appendix A.6).

Consider now $a^{SB}(\theta) > \widehat{a}(\theta)$. Differentiating (22) and solving for $a^{SB'}(\theta)$:

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

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

Nothing has been assumed about the sign of $Y_{122}(a(\theta),\theta)$, $Y_{112}(a(\theta),\theta)$ and then it is not clear if the monotonicity constraint holds. If it does then $\{[a^{SB}(\theta), T^{SB}(\theta)]; \underline{\theta} \leq \theta \leq \bar{\theta}\}$ is the optimal solution. All types choose different allocations and bunching types is not an issue.

If $a^{SB'}(\theta) > 0$ or $a^{SB'}(\theta)$ changes sign on the support Θ then $a^{SB}(\theta)$ is not the solution. The solution (see appendix A.8), 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). When it is not possible to separate the types, the regulator must keep into account that conservation payments could result in paying top transfers to each landowner. In this case, less land than expected may be conserved or the conserved units will be more costly than expected.

In what follows I assume that the monotonicity constraint holds and I compare the first-best cultivated surface with the second-best one. If $a(\theta) = a^{FB}(\theta)$ then via relation (9)

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

Instead if $a(\theta) = a^{SB}(\theta)$ rearranging (22)

$$Y_1(\bar{A} - a(\theta), \theta) = \frac{1}{p[1 - \bar{v} + q(\bar{v} - \underline{v})]} \left[c + \frac{B'(a(\theta))}{(1 + \lambda)} \right] + \quad (24)$$

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

Given the assumptions on $Y(\bar{A} - a(\theta), \theta)$ the following relation holds

$$a^{FB}(\theta) \geq a^{SB}(\theta) \forall \theta \in \Theta = [\underline{\theta}, \bar{\theta}] \quad (25)$$

Proposition 4 *Under asymmetric information, the surface allocated to agriculture within the program is never less than under symmetric information.*

This distortion is due to the presence of the factor

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

This term represents the effect of the information rent that must be paid to landholders in order to give them appropriate incentives to truthfully report their type. The scheme proposed decreases the surface of land conserved by higher land type holders to reduce the information rents paid to the lower land type holders. Note that there is no distortion only for the landholders who own the lowest type land (since $F(\underline{\theta}) = 0$).

3.2.3 Transfers

As proved above if the PIC is binding the contract proposed is separating. All landholders who conserve $\hat{a}(\theta)$ within the contract receive the same payment (see appendix A.6). If landholders whose land type is $\bar{\theta}$ conserve $\hat{a}(\bar{\theta})$ then all the landholders whose type lies in the interval $[\theta_1, \bar{\theta}]$ within which $a(\theta) = \hat{a}(\theta)$, will not be entitled to any transfer. Instead if $[\theta_1, \theta_2]$ is strictly included in $[\underline{\theta}, \bar{\theta}]$ then all the landholders laying in that interval will receive the same transfer calculated on θ_2 . In this case the landholders are paid but they do not modify their allocative choice. Adding the PIC to the maximization

problem guarantees at least that landholders will not use the transfer in order to convert more land, given that their budget constraints are less binding. Their compensation is then mainly due to the fact that at least they are revealing their type.

When the PIC is not binding and the monotonicity constraint holds the transfers can be computed simply substituting $a^{SB}(\bar{\theta})$ and $a^{SB}(\theta)$ into (18).

3.2.4 Further discussion and comparison with PSA program

The PSA program allows to any landowner to participate and to be paid a fixed amount, \bar{T} /ha/year. The GA fixes \bar{T} in order to attract lower opportunity cost land. In order to compare the PSA program with the program I have proposed in the previous sections, suppose that the GA is interested in developing the program in those lands where $\underline{\theta} \leq \theta \leq \bar{\theta}$. The PSA program is equivalent to offering the following contract schedule: $\{[\bar{a}(\theta), \bar{T} \cdot \bar{a}(\theta)]; \underline{\theta} \leq \theta \leq \bar{\theta}\}$ where $\bar{a}(\theta)$ is the surface that the landholders voluntarily decides to conserve under the program. It can be shown that this contract schedule is feasible in that it satisfies the IRC and is self-selecting (see appendix A.7). It follows

Proposition 5 *Compared with the PSA program, the optimal program increases social surplus from agricultural production and biodiversity conservation.*

Since the program $\{[a^{SB}(\theta), T^{SB}(\theta)]; \underline{\theta} \leq \theta \leq \bar{\theta}\}$ is the optimal or best feasible contract schedule, social surplus cannot be lower under this program than under the PSA program. In fact, when any payment is made in exchange for biodiversity conservation, social surplus will be greater under the optimal program because it is the unique solution to the GA's maximization problem.

4 A PARAMETRIC EXAMPLE

A GA that wants to implement the voluntary conservation scheme proposed needs specific information¹³ and its ability in reducing the cost due to the payment of information rents relies on the information which it can collect.

Knowing the private rent function, the possible shock outcomes and their probability and the distribution of types is the basic set of information that the regulator needs to define the landholder's incentive compatibility, individual rationality and perverse incentives constraints.

Let me now illustrate the characteristics of the mechanism under incentive compatibility by using an example. Represent the social benefit function by $B(a) = \beta a - \frac{a^2}{2}$, the agricultural production function by $Y(\bar{A} - a, \theta) = (\bar{A} - a)\theta - \frac{(\bar{A} - a)^2}{2}$, where $\beta > a$, $\underline{\theta} > \bar{A} - a$ and $\bar{\theta} \leq \bar{A} + \frac{c}{p[1 - \bar{v} + q(\bar{v} - \underline{v})]}$. The probability distribution function of θ is a uniform distribution function and then $F(\theta) = \frac{\theta - \underline{\theta}}{\bar{\theta} - \underline{\theta}}$, $f(\theta) = \frac{1}{\bar{\theta} - \underline{\theta}}$.

¹³The implementation requires information about: 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.

Without any CP, the amount of land conserved is

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

where $k = [1 - \bar{v} + q(\bar{v} - \underline{v})]$.

With CP in place, first best allocations are given by

$$a^{FB}(\theta) = (\bar{A} - \theta) \frac{(1 + \lambda) pk}{1 + (1 + \lambda) pk} + \frac{\beta}{1 + (1 + \lambda) pk} + \frac{c(1 + \lambda)}{1 + (1 + \lambda) pk}$$

$$T^{FB}(\theta) = (\widehat{a}(\theta) - a^{FB}(\theta)) \left[pk(\bar{A} - \theta) - c \frac{(\widehat{a}(\theta) + a^{FB}(\theta))}{2} \right]$$

As proved above the PIC is not binding for full information allocations.

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

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

Second best allocations are then given by

$$a^{SB}(\theta) = (\bar{A} - \theta) \frac{(1 + \lambda) pk}{1 + (1 + \lambda) pk} + \beta \frac{1}{1 + (1 + \lambda) pk} +$$

$$+ c \frac{(1 + \lambda)}{1 + (1 + \lambda) pk} - (\theta - \underline{\theta}) \frac{pk\lambda}{1 + (1 + \lambda) pk}$$

Comparing $a^{SB}(\theta)$ with $a^{FB}(\theta)$ one can see how the asymmetry of information gives the landholders through the veil it imposes the possibility of conserving less land. The term representing the effect of the information rent is

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

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 landholders to correctly reveal their type. If $\theta = \underline{\theta}$ the surface conserved is as expected the first best one. To derive the transfer function one must determine at first $T^{SB}(\bar{\theta})$. Minimizing $\Pi(\bar{A} - a^{SB}(\bar{\theta}), \bar{\theta})$ subject to (16) with respect to $T(\bar{\theta})$, it follows

$$T^{SB}(\bar{\theta}) = \pi(\bar{A} - \widehat{a}(\bar{\theta}), \bar{\theta}) - \pi(\bar{A} - a^{SB}(\bar{\theta}), \bar{\theta})$$

$$= (\widehat{a}(\bar{\theta}) - a^{SB}(\bar{\theta})) \left[pk(\bar{A} - \bar{\theta}) - c \frac{(\widehat{a}(\bar{\theta}) + a^{SB}(\bar{\theta}))}{2} \right]$$

The transfer function is then given by

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

It should be noted that as expected $T^{SB'}(\theta) \leq 0$ and the contract proposed is separating. The value of the information is higher for those landholders whose private opportunity cost of conserving land is low. Given that the level of transfer is defined using the opportunity cost, this type of landholders have no incentive to reveal their true cost if an informational rent is not paid.

5 CONCLUSIONS

Compensating landowners who protect habitat and wildlife is an idea with increasing advocates among both landholders and conservationists. Paying landholders for not converting land could be seen as a form of social welfare rather than development. However, through programs as the PSA, governments can give incentives for the provision of a valuable commodity and propose biodiversity conservation as an alternative land use.

Costa Rica has been able to implement an elaborate, nationwide payments scheme for environmental services in relatively short time. However, the PSA program must overcome some potential weaknesses as the lack of targeting and the use of undifferentiated transfers¹⁴.

This paper presents a payment scheme that allows for the differentiation of the payments with respect to the cost of providing environmental services. Compared with the PSA program, this scheme increases social surplus from agricultural production and biodiversity conservation.

The CP scheme is designed in order to optimally allocate the resources available according to the social surplus maximization objective. The agricultural production is modelled as a risky activity allowing for the possibility of an exogenous shock that negatively affects the landholder's crop yield. To minimize the cost and maximize the surface conserved the correct revelation of the opportunity cost is necessary. This need arises from the recognition that rational landholders will select a contract that maximizes the sum of profits from agriculture and conservation payments. The first effect of landholder rationality on the optimal contract schedule is that payments must increase as landholders' allocative choices become more restricted; otherwise, there would be no incentive to participate in the program. The second effect is that landholders who report they have higher type land must be paid a lower transfer and allowed

¹⁴This failure could lead to under-paying for preferable land types or over-paying for less preferable ones negatively affecting the cost effectiveness of Conservation Programs (World Bank, 2000).

to conserve less land than landholders who report they have lower productive land. Otherwise, all landholders would report high productive land and the information rents to be paid to avoid misreporting would be too high. The sum of profits from agriculture and conservation payments must increase with land quality to guarantee the viability of the program.

The introduction of a constraint that obliges the landholders to conserve at least what they would conserve without contract allows controlling for the possibility of generating perverse incentives with the CP. Finally, the optimal contract schedule also accounts for the effect of the cost of raising funding for the payments.

A APPENDIX

A.1 Full information allocation

The lagrangian of the maximization problem in (8) is

$$L = B(a(\theta)) + (1 + \lambda) \pi(\bar{A} - a(\theta), \theta) - \lambda \Pi(\bar{A} - a(\theta), \theta) + \gamma(\theta) (\Pi(\bar{A} - a(\theta), \theta) - \pi(\bar{A} - \hat{a}(\theta), \theta)) + \phi(\theta) (a(\theta) - \hat{a}(\theta))$$

where $\gamma(\theta)$ and $\phi(\theta)$ are the multipliers. Necessary conditions for an optimum under complete information are

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

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

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

$$\gamma(\theta) (\Pi(\bar{A} - a(\theta), \theta) - \pi(\bar{A} - \hat{a}(\theta), \theta)) = 0, \quad \gamma(\theta) \geq 0 \quad (KT.3)$$

$$\phi(\theta) (a(\theta) - \hat{a}(\theta)) = 0, \quad \phi(\theta) \geq 0 \quad (KT.4)$$

From (KT.2), $\gamma(\theta) > 0$. This implies that (KT.3) holds only if the IRC binds always. Now, suppose that $a(\theta) = \hat{a}(\theta)$ and $\phi(\theta) \geq 0$; substituting (KT.2) and (3) into (KT.1), it follows

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

This result contradicts our assumption on $\phi(\theta)$ and then it must be null and the second constraint is always not binding. Substituting KT.2 into KT.1 it comes out the relation that must hold to define the optimal conserved surface in first best (9).

From (3) I derive that when $a(\theta) = \hat{a}(\theta)$

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

Instead from (9) when $a(\theta) = a^{FB}(\theta)$

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

Given the properties assumed for $Y(\bar{A} - a(\theta), \theta)$ and $B(a(\theta))$ the following relations hold:

$$\begin{aligned} Y_1(\bar{A} - a^{FB}(\theta), \theta) &> Y_1(\bar{A} - \hat{a}(\theta), \theta) \\ \bar{A} - a^{FB}(\theta) &< \bar{A} - \hat{a}(\theta) \\ a^{FB}(\theta) &> \hat{a}(\theta) \end{aligned}$$

A.2 Lemma 1

A contract schedule is incentive compatible only if the landholders 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:

$$\begin{aligned} \max_{\tilde{\theta}} \left[\Pi(\bar{A} - a(\tilde{\theta}), \theta) \right] &= p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y(\bar{A} - a(\tilde{\theta}), \theta) + \\ &\quad - c(\bar{A} - a(\tilde{\theta})) + T(\tilde{\theta}) \end{aligned} \quad (\text{A.2.1})$$

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

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

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

From (A.2.1) I derive condition (b) of Lemma 1. The GA must impose in her contract schedule that (A.2.2) holds for every θ ; if it holds also its derivative with respect to θ must be zero:

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

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

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

Since $Y_{12}(\bar{A} - a(\theta), \theta) > 0$ by assumption and $p[1 - \bar{v} + q(\bar{v} - \underline{v})] \geq 0$ then condition (a) follows.

Now, let me show that if the contract schedule satisfies (a) and (b) then incentive compatibility holds. For every θ and $\tilde{\theta} \in [\underline{\theta}, \bar{\theta}]$,

$$\Pi(\bar{A} - a(\theta), \theta) - \Pi(\bar{A} - a(\tilde{\theta}), \theta) \geq \int_{\tilde{\theta}}^{\theta} \frac{\partial \Pi(\bar{A} - a(\xi), \theta)}{\partial \xi} d\xi \quad (A.2.6)$$

where

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

From condition (b), $T'(\xi) = \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - a(\xi), \xi) - c\} a'(\xi)$, and substituting it into (A.2.7) I obtain:

$$\frac{\partial \Pi(a(\xi), \theta)}{\partial \xi} = -p[1 - \bar{v} + q(\bar{v} - \underline{v})] [Y_1(\bar{A} - a(\xi), \theta) - Y_1(\bar{A} - a(\xi), \xi)] a'(\xi) \quad (A.2.8)$$

If $\xi \in [\tilde{\theta}, \theta]$ with $\theta \geq \tilde{\theta}$ then $Y_1(\bar{A} - a(\xi), \theta) - Y_1(\bar{A} - a(\xi), \xi) \geq 0$ since $Y_{12}(\bar{A} - a(\theta), \theta) \geq 0$ by assumption. If Condition (a) holds then $a'(\theta) \leq 0$ and then with $\theta \geq \tilde{\theta}$ the integrand in (A.2.6) is nonnegative and $\Pi(\bar{A} - a(\theta), \theta) - \Pi(\bar{A} - a(\tilde{\theta}), \theta) \geq 0$. Using the same arguments, if $\theta \leq \tilde{\theta}$ then the integrand in (A.2.6) is non positive. But considering that in this case the integration is done backwards then it still follows $\Pi(\bar{A} - a(\theta), \theta) - \Pi(\bar{A} - a(\tilde{\theta}), \theta) \geq 0$.

A.3 Larger total rents for the higher type

This could be proved studying the total derivative of the program rent function (12):

$$\frac{\partial [\Pi(\bar{A} - a(\theta), \theta)]}{\partial \theta} = - [p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - a(\theta), \theta) - c] a'(\theta) + (A.3.1) \\ + p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_2(\bar{A} - a(\theta), \theta) + T'(\theta)$$

Substituting condition (b) into (A.3.1) and considering that $Y_2(\bar{A} - a(\theta), \theta) > 0$ it follows that

$$\frac{\partial [\Pi(\bar{A} - a(\theta), \theta)]}{\partial \theta} = p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_2(\bar{A} - a(\theta), \theta) > 0 \quad (\text{A.3.2})$$

A.4 Lemma 2

Via envelope theorem and using (4)

$$\begin{aligned} \frac{\partial [\pi(\bar{A} - \hat{a}(\theta), \theta)]}{\partial \theta} &= - \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - \hat{a}(\theta), \theta) - c\} \hat{a}'(\theta) + \\ &+ p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_2(\bar{A} - \hat{a}(\theta), \theta) \\ &= p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_2(\bar{A} - \hat{a}(\theta), \theta) > 0 \end{aligned} \quad (\text{A.4.1})$$

Within the program $a(\theta) \geq \hat{a}(\theta)$. Comparing (5) with (17) and knowing that $Y_{12}(\bar{A} - a(\theta), \theta) > 0$ it follows :

$$\frac{\partial [\pi(\bar{A} - \hat{a}(\theta), \theta)]}{\partial \theta} \geq \frac{\partial [\pi(\bar{A} - a(\theta), \theta)]}{\partial \theta} \quad (\text{A.4.2})$$

That is, $\Pi(\bar{A} - a(\theta), \theta) - \pi(\bar{A} - \hat{a}(\theta), \theta)$ is non increasing in θ .

Hence, if $\Pi(\bar{A} - a(\bar{\theta}), \bar{\theta}) - \pi(\bar{A} - \hat{a}(\bar{\theta}), \bar{\theta}) \geq 0$ then $\Pi(\bar{A} - a(\theta), \theta) - \pi(\bar{A} - \hat{a}(\theta), \theta) \geq 0$ for every $\theta < \bar{\theta}$.

A.5 Lemma 3

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

$$\begin{aligned}
T(\theta) &= T(\bar{\theta}) - \int_{\theta}^{\bar{\theta}} T'(\xi) d\xi & (A.5.1) \\
&= T(\bar{\theta}) - \int_{\theta}^{\bar{\theta}} \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - a(\xi), \xi) - c\} a'(\xi) d\xi \\
&= T(\bar{\theta}) + \int_{\theta}^{\bar{\theta}} \frac{d \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y(\bar{A} - a(\xi), \xi) - c(\bar{A} - a(\xi))\}}{d\xi} d\xi + \\
&\quad - \int_{\theta}^{\bar{\theta}} p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_2(\bar{A} - a(\xi), \xi) d\xi \\
&= T(\bar{\theta}) + \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y(\bar{A} - a(\bar{\theta}), \bar{\theta}) - c(\bar{A} - a(\bar{\theta}))\} + \\
&\quad - \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y(\bar{A} - a(\theta), \theta) - c(\bar{A} - a(\theta))\} + \\
&\quad - [1 - \bar{v} + q(\bar{v} - \underline{v})] \int_{\theta}^{\bar{\theta}} p Y_2(\bar{A} - a(\xi), \xi) d\xi \\
&= \Pi(\bar{A} - a(\bar{\theta}), \bar{\theta}) - \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y(\bar{A} - a(\theta), \theta) - c(\bar{A} - a(\theta))\} + \\
&\quad - [1 - \bar{v} + q(\bar{v} - \underline{v})] \int_{\theta}^{\bar{\theta}} p Y_2(\bar{A} - a(\xi), \xi) d\xi
\end{aligned}$$

Substituting (A.5.1) into (15)

$$\begin{aligned}
E_{\theta}[W] &= \int_{\underline{\theta}}^{\bar{\theta}} \{B(a(\theta)) + (1 + \lambda) [p(1 - \bar{v} + q(\bar{v} - \underline{v})) Y(\bar{A} - a(\theta), \theta) + \\
&\quad - c(\bar{A} - a(\theta))] \} f(\theta) d\theta + & (A.5.2) \\
&+ \lambda [1 - \bar{v} + q(\bar{v} - \underline{v})] \int_{\underline{\theta}}^{\bar{\theta}} \int_{\theta}^{\bar{\theta}} p Y_2(\bar{A} - a(\xi), \xi) d\xi f(\theta) d\theta - \lambda \Pi(\bar{A} - a(\bar{\theta}), \bar{\theta})
\end{aligned}$$

Integrating by parts the last term of $E_\theta [W]$

$$\begin{aligned}
E_\theta [W] &= \int_{\underline{\theta}}^{\bar{\theta}} \{B(a(\theta)) + (1 + \lambda) [p(1 - \bar{v} + q(\bar{v} - \underline{v})) Y(\bar{A} - a(\theta), \theta) + \\
&\quad - c(\bar{A} - a(\theta))] \} f(\theta) d\theta + \\
&\quad + \lambda [1 - \bar{v} + q(\bar{v} - \underline{v})] \int_{\underline{\theta}}^{\bar{\theta}} pY_2(\bar{A} - a(\theta), \theta) F(\theta) d\theta - \lambda \Pi(\bar{A} - a(\bar{\theta}), \bar{\theta}) \\
&= \int_{\underline{\theta}}^{\bar{\theta}} \{B(a(\theta)) + (1 + \lambda) [p(1 - \bar{v} + q(\bar{v} - \underline{v})) Y(\bar{A} - a(\theta), \theta) - c(\bar{A} - a(\theta))] \} + \\
&\quad + \lambda [1 - \bar{v} + q(\bar{v} - \underline{v})] pY_2(\bar{A} - a(\theta), \theta) \frac{F(\theta)}{f(\theta)} \} f(\theta) d\theta - \lambda \Pi(\bar{A} - a(\bar{\theta}), \bar{\theta}) \\
&\quad = (1 + \lambda) [1 - \bar{v} + q(\bar{v} - \underline{v})] \int_{\underline{\theta}}^{\bar{\theta}} \Phi[a(\theta), \theta] f(\theta) d\theta - \lambda \Pi(\bar{A} - a(\bar{\theta}), \bar{\theta})
\end{aligned} \tag{A.5.3}$$

To maximize (A.5.3) or (17) is equivalent.

A.6 Monotonicity constraint and transfers when $a^{SB}(\theta) = \hat{a}(\theta)$

An optimal second best program requires $a^{SB'}(\theta) \leq 0$. First, consider $a^{SB}(\theta) = \hat{a}(\theta)$. Totally differentiate (4)

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

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

$$\hat{a}'(\theta) = \frac{Y_{12}(\bar{A} - \hat{a}(\theta), \theta)}{Y_{11}(\bar{A} - \hat{a}(\theta), \theta)} < 0 \tag{A.6.1}$$

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

Substituting $\hat{a}(\theta)$ into condition (b) of lemma 1

$$T'(\theta) = \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - \hat{a}(\theta), \theta) - c\} \hat{a}'(\theta) = 0$$

If landholders whose land type is $\bar{\theta}$ conserve $\hat{a}(\bar{\theta})$ then

$$T^{SB}(\theta) = T^{SB}(\bar{\theta}) = 0 \tag{A.6.2}$$

and all the landholders whose type lies in the interval $[\theta_1, \bar{\theta}]$ within which $a(\theta) = \hat{a}(\theta)$, will then not be entitled to any transfer.

A.7 PSA program: IRC and ICC

Under the PSA program $T(\theta) = \bar{T} \cdot a(\theta)$ and the landholder voluntary chooses the surface, $\bar{a}(\theta)$, she wants to conserve. It follows that

$$\pi(\bar{A} - \bar{a}(\theta), \theta) + \bar{T} \cdot \bar{a}(\theta) \geq \pi(\bar{A} - \hat{a}(\theta), \theta) \quad (\text{A.7.1})$$

and the IRC is satisfied.

If conditions (a) and (b) of lemma 1 are satisfied then the PSA program is incentive compatible. The landholder's rent are given by

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

Maximizing (A.7.2) with respect to $\bar{a}(\theta)$ the landholder define the surface to be conserved. From the foc

$$Y_1(\bar{A} - \bar{a}(\theta), \theta) = \frac{c + \bar{T}}{p[1 - \bar{v} + q(\bar{v} - \underline{v})]} \quad (\text{A.7.3})$$

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

$$\bar{a}'(\theta) = \frac{Y_{12}(\bar{A} - \bar{a}(\theta), \theta)}{Y_{11}(\bar{A} - \bar{a}(\theta), \theta)} < 0 \quad (\text{A.7.4})$$

That is, condition (a) of lemma 1 holds.

If $T(\theta) = \bar{T} \cdot \bar{a}(\theta)$ then $T'(\theta) = \bar{T} \cdot \bar{a}'(\theta)$. Substituting $T'(\theta)$ into condition (b) of lemma 1 the following relation must hold to guarantee incentive compatibility

$$\bar{T} \cdot \bar{a}'(\theta) = \{p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - \bar{a}(\theta), \theta) - c\} \bar{a}'(\theta) \quad (\text{A.7.5})$$

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

$$\bar{T} = p[1 - \bar{v} + q(\bar{v} - \underline{v})] Y_1(\bar{A} - \bar{a}(\theta), \theta) - c \quad (\text{A.7.6})$$

A.8 Bunching types

Bunching arises if the monotonicity constraint does not hold. To study this case one could restate the problem in (17) as follows

$$\begin{aligned} \max_{a(\theta), \gamma(\theta)} & \int_{\underline{\theta}}^{\bar{\theta}} \Phi[a(\theta), \theta] f(\theta) d\theta \\ \text{s.t.} & \end{aligned}$$

$$\gamma(\theta) = a'(\theta) \quad (\text{C1})$$

$$\gamma(\theta) \leq 0 \quad (\text{C2})$$

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

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

From the Pontryagin principle:

$$\mu'(\theta) = -\frac{\partial H}{\partial a} = -\frac{\partial \Phi[a(\theta), \theta]}{\partial a(\theta)} f(\theta) \quad (\text{A.8.2})$$

$$\mu(\theta)\gamma(\theta) = 0, \quad \mu(\theta) \geq 0 \quad (\text{A.8.3})$$

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

Consider instead an interval $[\theta_m, \theta_M] \subseteq [\underline{\theta}, \bar{\theta}]$ where the monotonicity constraint is binding ($a'(\theta) = 0$). Now, $\gamma(\theta) = 0$ and $a(\theta)$ is constant and equal to k . Observing that on the left and on the right of $[\theta_m, \theta_M]$ (C2) is not binding and that $\mu(\theta)$ is continuous then $\mu(\theta_1) = \mu(\theta_2) = 0$. Integrating (A.8.2) on $[\theta_m, \theta_M]$:

$$\int_{\theta_m}^{\theta_M} \frac{\partial \Phi[k, \theta]}{\partial a(\theta)} f(\theta) d\theta = 0 \quad (\text{A.8.4})$$

or

$$\begin{aligned} & \int_{\theta_m}^{\theta_M} \left\{ pY_1(k, \theta) f(\theta) + \frac{\lambda}{(1+\lambda)} pY_{12}(k, \theta) F(\theta) \right\} d\theta \\ &= \int_{\theta_m}^{\theta_M} \frac{1}{1 - \bar{v} + q(\bar{v} - \underline{v})} \left[\frac{B'(\bar{A} - k)}{(1+\lambda)} + c \right] f(\theta) d\theta \end{aligned} \quad (\text{A.8.5})$$

One could compute the unknown θ_m, θ_M and k , solving the system formed by (A.8.5) and $k = a^{SB}(\theta_m) = a^{SB}(\theta_M)$.

To summarize if $a'(\theta) > 0$ on the whole support, Θ , then the agency will bunch types. All landholders will retire the same amount of land, $a(\theta) = k$, and receive the same transfer $T(\bar{\theta})$. Since landholder's profit is costly for the agency then the optimal transfer, $T^{SB}(\bar{\theta})$, is such that $\Pi(\bar{A} - k, \bar{\theta}) = \pi(\bar{A} - k, \bar{\theta})$. There is no alternative for the regulator if she wants to keep feasible the program (lemma 2 and proposition 3). 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 landholders retire the same amount of land and get the same transfer.

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