Preference heterogeneity, asymmetric information, and the inevitability of informational rents in environmental subsidy programs*

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Abstract

We analyze the design of an environmental policy program in which agents are compensated for the amount of environmental services they provide. We assume that agents differ only in the rate at which they discount the future. Time preference heterogeneity implies that agents value specific environmental policies differently for two reasons. First, differences in discount rates imply that agents differ in how they value a particular stream of per-period benefits and costs. Second, decisions like how much to invest in abatement technologies or in land quality are influenced by time preferences, and differences in specific abatement technologies or land qualities can make environmental protection more or less costly – and hence the stream of per-period benefits and costs may differ between agents too. Contrary to conventional wisdom, we show that the complete information menu of environmental policy contracts can be incentive compatible in the presence of information asymmetries, and we determine the circumstances under which this is the case when investments are sunk at the time the government initiates the environmental policy program, and also when they can be adjusted.

Key words: Asymmetric information, adverse selection, advantageous selection, countervailing incentives, mechanism design.

JEL Codes: D82, H23, Q57.

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1 Introduction

Subsidies are frequently used by governments to achieve environmental objectives – to stimulate firms to invest in abatement technologies in the presence of adoption spillovers, to induce farmers to supply nature conservation services on their land, etc. (Parry 1998, Engel et al. 2008). Participation in subsidy schemes is typically voluntary, and hence governments need to ensure that the subsidies offered are sufficiently generous that all agents who should participate in the program decide to do so – subsidies offered to these agents must not be smaller than the costs they incur when providing the environmental service. But the payments should also not be too generous because raising funds for subsidy programs typically gives rise to efficiency losses elsewhere in the economy – after all, one of the most important sources of public funding is the (progressive) taxation of labor incomes that distorts, among others, labor-leisure decisions (Mirrlees 1971, Browning 1987, Ballard and Fullerton 1992). Subsidies are thus not just mere transfers from the tax payer to the agent, and hence the government faces a trade-off between environmental benefits of a program and the associated costs of distortionary taxation.[1]

Uniform subsidy schemes tend to be quite inefficient as they necessarily result in overly generous compensation payments to agents who can supply the requested environmental services at relatively low cost. A menu of incentive-compatible contracts can be designed to mitigate this inefficiency. Here, agents can choose from a menu of subsidy schemes, where each scheme (or contract) specifies the amount of environmental services that should be realized, as well as

[1] Of course, economists typically prefer taxing pollution or land conversion rather than subsidizing abatement or conservation, yet for political economy reasons governments typically prefer subsidies over taxes. While taxes would be able to trivially implement the optimum, we focus on how inefficiencies can be mitigated when agents cannot be taxed.

the amount of compensation the supplier would then receive. The design of these incentive-compatible contracts has received a substantial amount of attention in the literature, and optimal schemes have been identified that provide substantial efficiency improvements compared to uniform subsidy schemes (Wu and Babcock 1995, 1996; Ferraro 2001, 2008). Still, two inefficiencies typically remain. Low-cost agents (that is, those agents for whom providing environmental services is relatively cheap) are overcompensated for the services specified in their contract (they receive so-called ‘informational rents’), and the amount of environmental services required from the high-cost agents is distorted below the complete information level (see also Laffont and Tirole 1993, and Macho-Stadler and Perez-Castrillo 2009). To our knowledge, all but one study (Arguedas and van Soest 2011) analyze the design of these environmental schemes assuming that there is a single source of heterogeneity that causes agents’ participation costs to differ – the efficiency of technology they use, or the quality of their land.[2] Some production technologies are better suited to abate emissions than others (for example because they are more energy efficient), and hence the technology in use is a firm characteristic that affects whether a particular firm is a low-cost or a high-cost abater. Similarly, whether or not a farmer is a high-cost or low-cost supplier of nature conservation services on agricultural land may depend on the quality of that land – for example because the opportunity costs of conservation differ.

The key point we want to make in this paper is that the assumption that agents are identical in respects but one (the quality of their land, or the type of production technology they own) implies that the allocation of land and technologies over agents is assumed to be the outcome

[2] Examples of studies focusing on a single source of heterogeneity include Bourgeon et al. (1995), Smith (1995), Smith and Tomasi (1995, 1999), Wu and Babcock (1995, 1996), Rochet and Choné (1998), Moxey et al. (1999), and Mason (2013); see Chambers (2002) and Ferraro (2008) for overviews.

of an essentially random process – and this is not very plausible. We analyze how the optimal design of environmental programs changes if we assume that the agents' production technologies (land, or the vintage of capital employed) are not randomly distributed over the agents' population, but that they are the outcome of each individual agent's decision making process. Suppose that agents differ in their preferences with respect to the rate at which they discount the future. More patient entrepreneurs are likely to purchase more expensive abatement technologies that have lower marginal abatement costs – now, and in the future. And if land markets are not too imperfect, farmers with relatively low (high) rates of time preferences are more likely to end up on high (low) quality lands.[3] The notion that agents with different rates of time preference end up owning different abatement technologies or land qualities is important because it implies that agents actually differ in not just one, but in two respects. They face different per-period (marginal) benefits and costs of offering environmental services depending on the type of technology or the quality of the land they own. And they also differ in how much they value a specific stream of per-period benefits and costs, resulting in different net present values of environmental cost and benefit flows.

In this paper we show that if agents differ in more than one respect, the complete information solution of the government's environmental policy problem can be incentive compatible even if the differences are caused by the same fundamental factor – heterogeneity in time preferences.

[3]Consider the following toy model. Assume that the per-period agricultural profits π are an increasing function of land quality, α: $\pi = f(\alpha, \bullet)$, with $\partial f/\partial\alpha = f' > 0$. Using ρ to denote the farmer's discount rate, the net present value (over an infinite time horizon) of agricultural land with land quality α is $V = f(\alpha, \bullet)/\rho$. The marginal value of land quality is $\partial V/\partial\alpha = f'/\rho$, and this value is higher the lower is ρ (because $\partial^2 V/\partial\alpha\partial\rho = -f'/\rho^2 < 0$). Hence, if land can be purchased and sold, the more patient farmers (i.e., those with a lower discount rate) tend to be willing to pay more for high quality land than impatient farmers. Theory thus predicts that farmers who own higher quality land, have lower rates of time preference. Empirical support for this prediction can be found in Bocquého and Jacquet (2010), who show that in moving from a traditional cropping system to the production of biofuels (which requires large up-front investments) time preferences significantly influence investment decisions.

The analysis of endogenous technology choice (land quality, or abatement technology) is interesting in itself because it contradicts the information economics literature's typical conclusion that the first-best (or complete information) solution cannot be implemented in the presence of information asymmetries. But if technologies and land qualities are non-randomly distributed between agent types at the moment at which the government initiates its environmental program, one can wonder whether agents will not adjust their technology choices or land management decisions as soon as the environmental policy is in place. For any given menu of contracts offered by the government, agents may decide to purchase new abatement technologies, manage their lands differently, or relocate to different lands. So the question is whether the complete information menu of environmental services contracts can still be incentive compatible if we assume that agents can adjust their production technologies in response to the introduction of the environmental program (so that all decisions are truly endogenous). Answering this question is the second contribution of this paper.

Other studies have analyzed the role of preference heterogeneity in mechanism design problems; see for example Wirl (1999, 2000), Peterson and Boisvert (2004), and Mason (2013). We contribute to the insights obtained in these papers by noting that this heterogeneity implies that agents differ in two respects – not just in how they value a particular stream of profits or what technology (land quality, or capital vintage) they own, but both. Our paper also builds on earlier research on 'counterveiling incentives' (see for example Lewis and Sappington 1989, Maggi and Rodriquez-Claire 1995) that shows that informational rents can be avoided if fixed and variable costs are negatively correlated (see also Baron and Myerson 1982, Araujo and Moreira 2000, Rochet 2009, and Arguedas and van Soest 2011). In this paper we show that the complete information solution can be incentive compatible even if the upfront investment costs are endogenous – as long as the regulated agents differ in the rate at which the discount the future.

Our paper is also related to the literature on ‘advantageous selection’ in insurance markets, which addresses the issue why low-risk individuals may purchase more insurance than high-risk individuals. One explanation of this negative correlation is that risk-averse individuals are more likely to reduce the hazard so that they are low risk, but that they are also more likely to purchase insurance (Hemenway 1990, p. 1064). While other explanations exist, preference heterogeneity can thus explain the empirical observation that people with higher insurance coverage are not found to be more accident-prone (in case of automobile insurance, see Chiappori and Salanié 2000, Saito 2006), or are even found to be less accident-prone (in case of credit card theft, life insurance and health insurance; cf. de Meza and Webb 2001, Cawley and Philippson 1999, and Finkelstein and McGarry 2006). This literature focuses on explaining why insurance markets exist, whether or not there is room for ‘cherry picking’ (because of the high profits associated with selling more insurance to low-risk agents; Chiappori and Salanié 2000), and whether or not pooling equilibria exist (compare for example de Meza and Webb 2001 and de Donder and Hindriks 2009). Our paper is complementary to this literature as we analyze whether the ‘double cost of separating’ (with one type of agents receiving informational rents, and the other type undertaking less of the socially desired activity than absent information asymmetries) is unavoidable in contracts between a regulator and the regulated agents.

We believe that the idea behind our paper is sufficiently generic that it applies to a wide range of environmental problems – and maybe to non-environmental problems as well. However, for ease of exposition and because of data availability, we decided to couch our model in the “nature conservation” literature. Conservation payment programs have become increasingly popular as an instrument to protect nature (Pattanayak et al. 2010). Private landowners, most often farmers, are offered financial compensation in exchange for the provision of environmental services such as creating habitat for plants and/or wildlife, planting specific shrubs and trees to sequester carbon, etc. As discussed above, the design of these conservation schemes has been studied assuming that there is a single source of heterogeneity – differences in land quality – that causes the farmers' participation costs to differ. We show that if land quality is endogenous, the complete information solution can be incentive compatible under asymmetric information even if farmers differ in essentially just one variable – the rate at which they discount the future.

The setup of the paper is as follows. In section 2 we present a highly stylized model, which assumes that land quality is ex-ante homogenous but can differ ex-post depending on the land owner's investment decisions.[4] In section 3, we solve the mechanism design problem assuming that farmers move first, so that the government can take the preference-induced differences in land quality as given. In section 4, we consider the alternative scenario in which the farmers can adjust their land quality decisions in response to the government's announcement of the specifics of the conservation program. That means that in this section the government is assumed to move first, and the farmers second – and hence the government needs to design the menu of contracts taking into account the farmers' best response. We find that the complete information solution can be incentive compatible both when the farmers move first (as analyzed in section 3), but also when they move second (as analyzed in section 4). Next, while most assumptions in this paper are well-grounded in economic theory, it is interesting to see whether we can find empirical evidence supporting them. For this purpose we make use of a data set collected by Tesfaye and

[4]Hence, we do not explicitly analyze the consequences of land quality being ex-ante heterogeneous. Compared to just assuming that land itself is homogenous while land quality investments are endogenous, modeling a land market with plots of differing quality is much more involved while the results are not likely to be qualitatively different. Whether this is indeed the case, is left for future research.

Brouwer (2012) that allows us to test whether the most important assumptions (among which the relationship between a farmer's rate of time preference and the quality of his land) hold in practice. Section 6 concludes.

2 The model

We consider a group of N farmers who differ in the rate at which they discount the future. Farmer i's rate of time preference (or discount rate) is denoted by $\rho_i > 0$. Time preferences are a private characteristic of farmers. For simplicity, we assume there are two types of farmers, patient farmers (identified using subscript P) and impatient farmers (subscript I), such that $\rho_P < \rho_I$. The number of patient (impatient) farmers in the population is given by q_P (q_I), such that $q_P + q_I = N$.

Each farmer owns one plot of land. All plots are assumed to be (ex-ante) homogenous, but farmers can improve the quality of their land by, for example, setting up irrigation systems, investing in mounds and ridges to better retain top soils, etc. We use α_i to denote land quality, which is thus a decision variable for farmer i.

Land quality affects the returns to agriculture. For simplicity, we assume that the per-period returns to agriculture equal $P\alpha_i$ (where P is the sales price of agricultural produce) while the investment costs in land quality are $\alpha_i^2/2$. That means that the net present value of the returns to agriculture, $r_i(\alpha_i)$, is equal to

$$r_i(\alpha_i, \rho_i) = \frac{P\alpha_i}{\rho_i} - \frac{\alpha_i^2}{2}.^5 \quad (1)$$

The government aims to set up a conservation program. This program requires each farmer

[5] Note that the net present value of the agricultural revenues is calculated using farmer-specific discount rates. We thus implicitly assume that access to capital markets is less than perfect.

i to provide a certain amount of conservation services (denoted by $b_i > 0$) in exchange for a compensation payment or subsidy (denoted by $S_i > 0$).

On-farm conservation typically gives rise to two types of costs: up-front investments (for example in creating suitable habitat), and per-period maintenance costs. We assume that the up-front investment costs are a function of the amount of conservation services provided by farmer i, b_i, but also of land quality, α_i. More specifically, we assume that the up-front investment costs are equal to $b_i^2(\varphi - \alpha_i)/2 \geq 0$, where φ is a technical parameter that is sufficiently large such that $\varphi > \alpha_i$ for the relevant range of land quality levels α_i. Investment costs are thus increasing and convex in b_i, and for given b_i they decrease linearly in α_i.[6] An example in point is nature conservation in arid regions or in regions with poor soils – better irrigated lands or better preserved soils facilitate creating valuable habitat (see for example Garrido et al. 2006 for the case of Spain). But conservation also requires a certain amount of maintenance in every period. Assuming that the per-period maintenance costs are γ per unit of conservation services supplied, the net present value of the conservation expenditures as evaluated by farmer i is equal to

$$c_i(b_i, \alpha_i, \rho_i) = \frac{b_i^2}{2}(\varphi - \alpha_i) + \frac{\gamma b_i}{\rho_i}. \tag{2}$$

For any level of conservation services provided (b_i), the net present value of the benefit

[6]If $\varphi < \alpha_i$ for some realizations of α_i, the up-front conservation investment costs would decrease in the amount of conservation provided (b_i) – and this is not very plausible. The minimum level of φ (given the other assumptions and specifications) is formally stated in conditions (9) and (23) below.

and cost flows as perceived by farmer i is equal to $\pi_i(b_i, \alpha_i, \rho_i) \equiv r_i(\alpha_i, \rho_i) - c_i(b_i, \alpha_i, \rho_i)$.[7,8] Farmer participation is assumed to be voluntary, and that means that farmer i only wants to offer conservation services $b_i > 0$ if the value she attaches to the stream of net payoffs when participating, is larger than the value she obtains when not participating. Using S_i to denote the amount of compensation received by farmer i when she participates in the program, her total payoffs are equal to $S_i + \pi_i(b_i, \alpha_i, \rho_i)$ when supplying $b_i > 0$. And let us use $\pi_i^0 \equiv \pi_i(0, \alpha_i, \rho_i)$ to denote her profits when she decides not to participate. Hence, for any required level of b_i, the government must provide subsidies S_i such that

$$S_i \geq \pi_i^0 - \pi_i(b_i, \alpha_i, \rho_i), \tag{3}$$

and this is the program's participation constraint for all $i = \{P, I\}$.

The government aims to maximize a social welfare function that consists of three components. First, conservation yields benefits to society. We assume the net present value of the associated conservation benefits are equal to $E\left(\Sigma b_i\right)/\rho_S$, where ρ_S is the social discount rate[9] and where $E\left(\bullet\right)$ is the function that translates the total amount of conservation achieved by the agricultural sector, Σb_i, into an amount of per-period benefits obtained. For simplicity, we

[7] Specifications (1) and (2) are chosen for simplicity, not because they are particularly realistic. For example, these specifications imply that higher output prices (P) do not increase the opportunity costs of providing conservation services – prices only affect conservation costs indirectly because they affect land quality investments. A specification of the revenue function that does capture these opportunity costs is the following: $r_i(b_i, \alpha_i, \rho_i) = \frac{P\alpha_i}{\rho_i}(1 - b_i) - \frac{\alpha_i^2}{2}$, and b can then be thought of as the share of farmer i's land that is allocated to conservation. All insights obtained using (1) and (2) carry over to the case in which (1) is replaced by the above revenue function. We will come back to this in both sections 3 (footnote 12) and 4 (footnote 16).

[8] Differences in rates of time preferences thus affect how farmers value money flows differently, and also their optimal investments. If, for example, the impatient farmers can borrow against their future income flows, they would choose the optimal investments based on the prevailing real interest rate, and then borrow money from the bank to increase their instantaneous consumption levels. Obviously, such a mechanism would give rise to all sorts of moral hazard issues, and hence the assumption of imperfect capital markets is quite likely to be met in practice.

[9] Note that ρ_S is not directly related to ρ_I and ρ_P – at least not necessarily so. Farmers make up only a small share of society, and the (properly weighted) average discount rate in society may be higher than that of the impatient farmers ($\rho_S > \rho_I$), below that of the patient farmers ($\rho_S < \rho_P$), or anything in between.

assume that the conservation benefits are linear in the amount of conservation supplied by all farmers, so that $E(\bullet) = k\sum_{i\in\{P,I\}} q_i b_i$, where k denotes the constant marginal benefits of conservation services provided.

The second component of the social welfare function is the sum of the net present values of the farmers' profits $\sum_{i\in\{P,I\}} q_i \pi_i$; cf. (1) and (2). The higher b_i, the larger the conservation costs, and hence the lower is π_i.[10] The third component arises because we assume that the compensation payments (or subsidies, S_i) are not mere transfers from the tax payer to the farmer, but that there are non-zero costs of raising funds. Raising funds for the government budget usually requires imposing distortionary taxes, and we assume that the marginal costs of raising funds are constant and equal to t (Mirrlees 1971). Hence, the third component in the government's social welfare function is a cost equal to $\sum_{i\in\{P,I\}} tq_i S_i$. Summing up, social welfare (W) is defined as

$$W = k\sum_{i\in\{P,I\}} q_i b_i/\rho_S + \sum_{i\in\{P,I\}} q_i \pi_i - t\sum_{i\in\{P,I\}} q_i S_i. \quad (4)$$

Under complete information, the government would set the conservation policy (S_i, b_i) to maximize social welfare (4), subject to the participation constraints presented in (3). However, as stated above, (im)patience is a private characteristic of farmers that is unobservable to the government, and the same holds for the quality of their land, as is typically assumed in this literature.[11] We assume the government knows the proportion of farmers with discount rates ρ_P

[10] Note that π_i denotes the net present value of land use as perceived by land owners of type i (cf. (1) and (2)). One can also argue that producer surplus should be evaluated using the social discount rate (ρ_S) rather than using the type-specific rates (ρ_i; $i = P, I$). Because land owners' participation and their choice of contract is based on their individual discount rates, it is mathematically more convenient to include π_i in the social welfare function; evaluating profit flows based on ρ_S complicates the analysis without affecting the qualitative results.

[11] In general, managerial decisions such as setting up irrigation systems, investing in mounds and ridges to better retain top soils or deciding on pond depth for underground water collection clearly affect land quality, but can only be observed at (prohibitively) high cost to the regulator; see for example Llamas and Martínez-Santos (2005) and Martínez-Santos and Martínez-Alfaro (2010). Therefore, we assume that (ex-post) land quality is also private

and ρ_I in the population, and also the type-specific cost and revenue functions (1) and (2). The challenge the government faces is to design a menu of conservation contracts targeted at each type $((S_P, b_P), (S_I, b_I))$ that maximizes social welfare function (4) while not only ensuring that all farmers participate in the program (see (3)) but also that each farmer (weakly) prefers the contract targeted at her type. These incentive compatibility constraints are:

$$S_i + \pi_i(b_i, \alpha_i, \rho_i) \geq S_j + \pi_i(b_j, \alpha_i, \rho_i) \tag{5}$$

for all $i, j = \{P, I\}$ and $i \neq j$. We assume that if (5) holds with equality for farmers of type i, they choose the contract designed for their type (S_i, b_i) .

We are interested in analyzing under what circumstances the complete information conservation policy satisfies the incentive compatibility conditions expressed in (5). Clearly, the solution is trivial if it is socially optimal for either no or just one farmer type to engage in conservation. A necessary condition for the problem to be non-trivial is that the discounted marginal social benefits of conservation (taking into account the costs of raising funds), $(\rho_S(1+t))^{-1}k$, are larger than the discounted value of the first unit of conservation costs incurred by either type of land owner, $\partial c_i / \partial b_i|_{b_i=0} = \gamma/\rho_i$; cf. (2). Using G to denote $(\rho_S(1+t))^{-1}k$ and noting that $\rho_I > \rho_P$, we assume throughout the remainder that the following condition always holds:

$$G \equiv \frac{k}{\rho_S(1+t)} > \frac{\gamma}{\rho_P}. \tag{6}$$

We can envisage two scenarios regarding the timing of the farmers' investments in land quality. The first scenario is the case where conservation policies are introduced while farmers chose their land qualities sometime in the past. This scenario roughly reflects how conservation

information for the farmers involved. If the regulator could (costlessly) verify land quality, she would be able to infer the discount rate of every farmer, and could trivially implement the complete information solution.

programs are currently introduced – they are still a relatively new policy instrument. Farmers are endowed with land of a specific quality because of the investment decisions they made in the past, and the government introduces a conservation program while taking heterogeneity in land quality as given. In the second scenario we assume the government designs the program taking into account the possibility that farmers adjust their land quality investments in response. This is likely to be the case in the future, for example when farmers need to renew their land quality investments while the conservation program is still in place. The two scenarios thus differ in who moves first: with the farmers first choosing their land quality and then the government introducing the conservation policy in the first scenario (see section 3), and the reverse in the second (see section 4).

3 Optimal conservation when land quality is predetermined

3.1 Land quality investment

The government designs and introduces the conservation program while farmers chose their land quality α_i sometime in the past. We assume that at the time farmers made their land quality investments they were unaware of the possibility that the government might initiate a nature conservation program. That means that they chose α_i and b_i to maximize the net present value of land use; cf. (1) and (2). Conservation is costly while it does not yield any private benefits, and hence all farmers choose $b_i = 0$ independent of their rate of time preference. That means that maximizing the net present value of land use requires choosing α_i to maximize (1). In this scenario, the optimal land investments and associated net present values of agricultural returns and profits are

$$\alpha_i^F = \frac{P}{\rho_i}, \quad \pi_i^F = r_i^F = \frac{P^2}{2\rho_i^2}, \tag{7}$$

where superscript F indicates the optimal value when every farmer's land quality is fixed (or predetermined) when the conservation program is announced. Recall that π_i^0 denotes farmer i's profits when she does not participate in the program; cf. (3). In that case, her profits are equal to π_i^F (cf. (7)), and hence $\pi_i^0 = \pi_i^F = r_i^F$. If she does participate, the net present value of her revenues are still r_i^F, but she incurs the costs associated with conservation effort $b_i > 0$. That means that in this case with fixed land qualities, the foregone profits associated with conservation effort are equal to the conservation costs incurred: $\pi_i^0 - \pi_i(b, \alpha_i^F, \rho_i) = c_i(b, \alpha_i^F, \rho_i)$; cf. (1) and (2). Substituting α_i^F from (7) into (2), we see that one single source of heterogeneity, differences in time preferences, causes the cost functions of the two types to differ in two respects. Land qualities (α_i^F) are type-dependent and hence the investment costs of conservation $\left(b_i^2 \left(\varphi - \alpha_i^F\right)/2\right)$ also differ between the two types. And differences in the rate of time preferences imply that farmers also differ in the way they evaluate the flow of the per-period maintenance costs ($\gamma b_i/\rho_i$) associated with conservation. The farmers' participation constraints (3) can hence be written as:

$$S_i\left(b_i\right) \geq c_i(b_i, \alpha_i^F, \rho_i) = \frac{b_i^2}{2}\left(\varphi - \frac{P}{\rho_i}\right) + \frac{\gamma b_i}{\rho_i}. \tag{8}$$

Regarding (8), note that $\alpha_i^F = P/\rho_i$ (cf. (7)), while the conservation cost function (2) assumes that $\varphi > \alpha_i^F$. Because $\rho_I > \rho_P$, we assume that the following holds throughout the paper:

$$\varphi > \frac{P}{\rho_P}. \tag{9}$$

Combining (9) and (6) implies that a necessary condition for the model to be valid in this first scenario is that

$$\rho_P > \max\left\{\frac{P}{\varphi}, \frac{\gamma}{G}\right\}. \tag{10}$$

Our strategy is as follows. We first derive, in section 3.2, the optimal solution of the government's maximization problem under complete information – that is, when incentive compatibility is not (or is assumed not to be) an issue. Next, in section 3.3 we analyze under what circumstances the complete information solution is incentive compatible if the government only knows the distribution of discount rates, but does not know the discount rate of each individual farmer.

3.2 The complete information solution

Absent information asymmetries, the government would choose a menu of contracts, (S_P, b_P) and (S_I, b_I), to maximize social welfare (4), taking into account the farmers' participation constraints (8). The menu of contracts that solves the government's maximization problem under complete information is given in Proposition 1.

Proposition 1 *The complete information menu of conservation levels and subsidies when land quality is predetermined, (S_I^{*F}, b_I^{*F}) and (S_P^{*F}, b_P^{*F}), is given by:*

$$b_i^{*F} = \frac{1}{\rho_i}\left(\frac{\rho_i G - \gamma}{\varphi - \alpha_i^F}\right) = \frac{\rho_i G - \gamma}{\rho_i \varphi - P}, \text{ and} \tag{11}$$

$$S_i^{*F} = \frac{\gamma b_i^{*F}}{\rho_i} + \frac{\left(b_i^{*F}\right)^2}{2}\left(\varphi - \alpha_i^F\right) \tag{12}$$

where $\alpha_i^F = P/\rho_i$ and $G \equiv (\rho_S(1+t))^{-1}k$.

Proof: see Appendix A. ■

Note that $b_i^{*F} > 0$ because of (10). The complete information conservation efforts (b_P^{*F}, b_I^{*F}) satisfy the familiar condition that the marginal conservation costs of each type are equal to the marginal benefits of conservation. That implies that the conservation effort is such that the marginal conservation costs are the same across the two farmer types: $c'_P(b_P^{*F}) = c'_I(b_I^{*F}) = G$. And because the costs of raising funds are strictly positive, the complete information solution also requires that the subsidies offered (S_P^{*F}, S_I^{*F}) exactly cover the conservation costs incurred (that is, participation constraints (8) are binding).

3.3 Is $(S_P^{*F}, b_P^{*F}), (S_I^{*F}, b_I^{*F})$ ever incentive compatible?

Information about each farmer's type is private, and hence the government can not just maximize (4) subject to (8); the incentive compatibility constraints (5) need to hold too. In this subsection we analyze whether (and under what circumstances) the complete information policy ((11) and (12)) is incentive compatible in the presence of these information asymmetries. Using (1), (2) and (7), we have $\pi_i(b, \alpha_i^F, \rho_i) = \frac{P^2}{2\rho_i^2} - \frac{b^2}{2}\left(\varphi - \frac{P}{\rho_i}\right) - \frac{\gamma b}{\rho_i}$. Substituting this expression into (5) and cancelling terms, we have:

$$S_i^{*F} - \frac{\gamma b_i^{*F}}{\rho_i} - \frac{\left(b_i^{*F}\right)^2}{2}(\varphi - \alpha_i^F) \geq S_j^{*F} - \frac{\gamma b_j^{*F}}{\rho_i} - \frac{\left(b_j^{*F}\right)^2}{2}(\varphi - \alpha_i^F) \tag{13}$$

for all $i, j = \{P, I\}$ and $j \neq i$.

Substituting (11) and (12) into (13), we obtain the following result:

Proposition 2 *The complete information conservation program,* (S_I^{*F}, b_I^{*F}) *and* (S_P^{*F}, b_P^{*F})*, is incentive compatible if and only if:*

$$b_I^{*F} \leq \frac{2\gamma}{P} \leq b_P^{*F}. \tag{14}$$

Proof: see Appendix B. ■

The intuition behind this result is straightforward. Because $t > 0$, the complete information solution requires that there are zero informational rents (cf. (12)); $S_i^{*F} = c_i(b_i^{*F}, \alpha_i^F, \rho_i)$.

Next, the incentive compatibility constraints (13) require that $S_i^{*F} - c_i(b_i^{*F}, \alpha_i^F, \rho_i) \geq S_j^{*F} - c_i(b_j^{*F}, \alpha_i^F, \rho_i)$. Combining the two, we have: $0 \geq c_j(b_j^{*F}, \alpha_j^F, \rho_j) - c_i(b_j^{*F}, \alpha_i^F, \rho_i)$ for $i, j = \{P, I\}$ and $j \neq i$. Hence, the complete information solution is incentive compatible if and only if (i) $c_P(b_P^{*F}, \alpha_P^F, \rho_P) \leq c_I(b_P^{*F}, \alpha_I^F, \rho_I)$ and (ii) $c_I(b_I^{*F}, \alpha_I^F, \rho_I) \leq c_P(b_I^{*F}, \alpha_P^F, \rho_P)$. That means that the cost functions of the two types should intersect, with the patient farmers having lower (higher) total conservation costs at b_P^{*F} $\left(b_I^{*F}\right)$ than the impatient farmers. Viewing (2), we see that $c_I = c_P$ if $b = 0$, but also possibly for $b > 0$. Patient farmers have lower up-front conservation investment costs ($b^2 \left(\varphi - \alpha_i^F\right)/2$) for every level of b (because α_i^F is larger the lower is ρ_i; cf. (7)). But patient farmers also have higher (valuations of) conservation maintenance costs (because $\gamma b/\rho_i$ is higher the lower is ρ_i). So, for b sufficiently small (large), the total conservation costs incurred by the patient farmers tend to be larger (smaller) than those incurred by the impatient farmers. Indeed, substituting (7) into (2) we find that $c_P\left(b, \alpha_P^F, \rho_P\right) = c_I\left(b, \alpha_I^F, \rho_I\right)$ if $b = \left\{0,\ \tilde{b} \equiv 2\gamma/P\right\}$.

These results are illustrated in Figure 1. The total conservation cost functions c_P and c_I intersect twice. For $b \in \left\langle 0, \tilde{b}\right\rangle$ we have $c_P\left(b, \alpha_P^F, \rho_P\right) > c_I(b, \alpha_I^F, \rho_I)$, and the reverse holds for all $b > \tilde{b}$. The complete information solution is that b_P^{*F} and b_I^{*F} are such that the marginal conservation costs incurred by each type are the same and equal to $G \equiv k/(1+t)\rho_S$ (as indicated by the tangency lines in Figure 1), while farmers of each type receive compensation S_i^{*F} that exactly cover their conservation costs $c_i\left(b_i^{*F}, \alpha_i^F, \rho_i\right)$. If the complete information conservation levels are located on either side of $\tilde{b}$, we have $S_j\left(b_j^{*F}\right) < c_i\left(b_j^{*F}, \alpha_i^F, \rho_i\right)$ for all $\{i, j\} = \{P, I\}, j \neq i$, and hence each type makes a loss if they choose the contract intended for the other type. That means that the complete information menu of contracts is incentive compatible if and only if b_I^{*F} and b_P^{*F} are located on either side of the conservation level at which the two cost functions intersect.

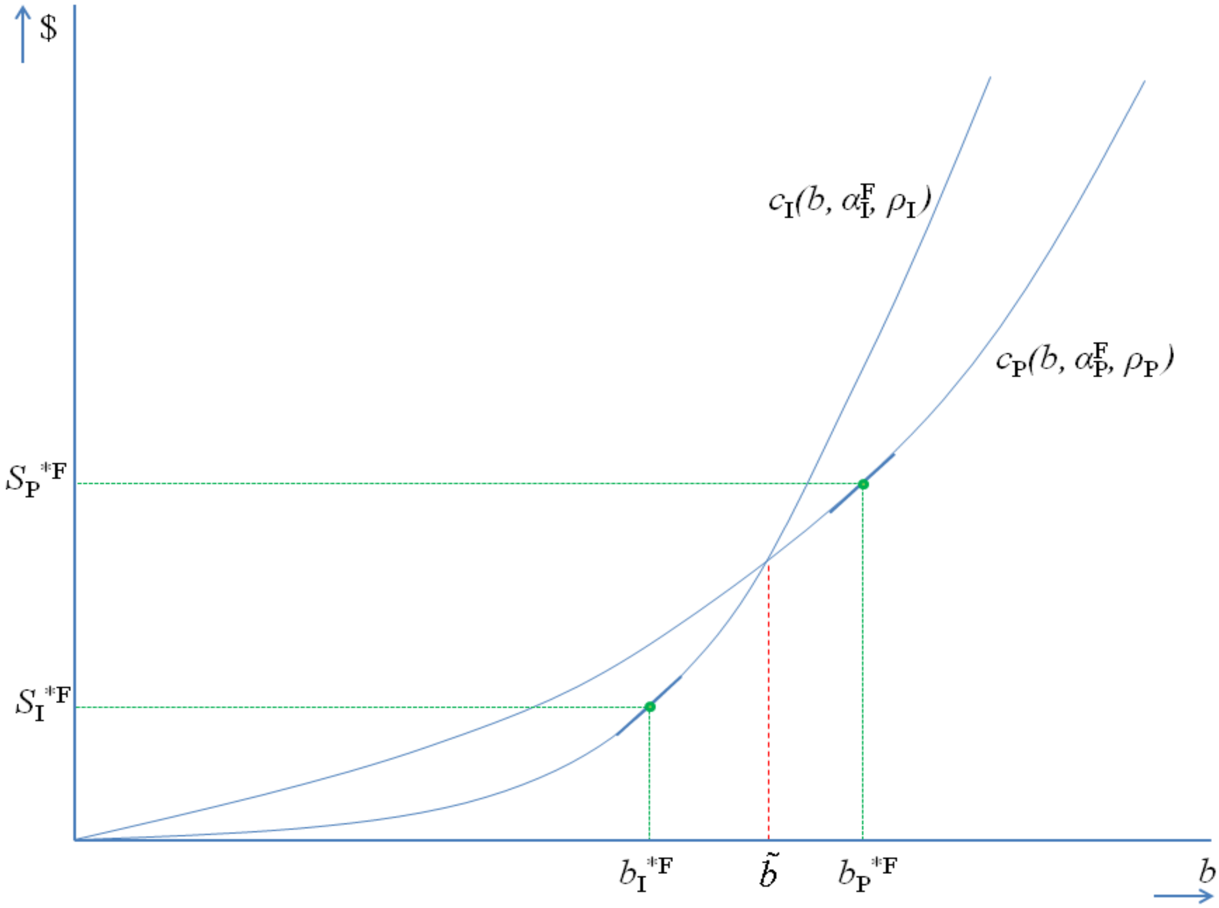

Figure 1: An example of a first-best menu of contracts (S_i^{*F}, b_i^{*F}) that is incentive compatible.

Whether the complete information solution is incentive compatible thus depends on whether the optimal conservation levels are located on either side of $\tilde{b}$. Proposition 3 states the parameter values for which the complete information solution is incentive compatible.

Proposition 3 *The complete information solution,* (S_P^{*F}, b_P^{*F}) *and* (S_I^{*F}, b_I^{*F})*, is incentive compatible if and only if*

$$\rho_P \leq \frac{P\gamma}{2\gamma\varphi - GP} \leq \rho_I. \tag{15}$$

Proof. Substituting the complete information conservation levels (11) into condition (14), we obtain (15). ■

Therefore, there exists a (non-empty) set of parameter values G, γ, φ, P, ρ_P and ρ_I such that the complete information solution is incentive compatible.[12,13] For the sake of completeness, we also offer the second-best solution in Appendix D. In the next subsection, we explore how likely it is that condition (15) holds.

3.4 Graphical analysis when land quality is predetermined

In this subsection, we construct a graphical example to see how likely it is that the complete information solution is incentive compatible – what is the proportion of admissible (ρ_P, ρ_I) combinations for which condition (15) is met? We arbitrarily set $k = 2$, $\rho_S = 0.1$, $t = 0.05$, $\gamma = 0.9$, $\varphi = 15$, and $P = 1.1$. In Figure 2 the shaded rectangle represents the combinations of ρ_P and ρ_I for which the complete information menu is incentive compatible, while the grey triangle represents all admissible combinations of ρ_P and ρ_I. Regarding the latter, by definition we have $\rho_I > \rho_P$ and hence the admissible (ρ_P, ρ_I) space is above the 45-degrees line. Next, the values of ρ_P and ρ_I cannot be too low because condition (10) needs to hold. For the chosen parameter values, this condition requires that $\rho_P > \max\{P/\varphi, \gamma/G\} = P/\varphi = 0.073$.[14] While

[12] A sufficient condition for (15) to be non-empty is that (6) is more binding than (9).

[13] The current specification means that the first-best solution can be incentive compatible if there are two farmer types, but not when there are three or more types – because $\tilde{b}$ is a constant that does not depend on farmers' discount rates. When we use the more general revenue specification presented in footnote 6, we find that $\tilde{b}_{ij} = \frac{2\gamma}{P} + 2P\left(\frac{1}{\rho_i} + \frac{1}{\rho_j}\right)$. Consider $\rho_j = \rho_i + v_{ij} > \rho_i$. Substituting this into $\tilde{b}_{ij}(\rho_i, \rho_j)$, we have $\partial\tilde{b}_{ij}/\partial\rho_i < 0$ – the non-trivial intersection point of the two cost functions of any two types of farmers is closer to the origin the more impatient the reference farmer type is. That means that with the more general revenue function, the first-best solution may still be incentive compatible even if there are more than two farmer types. For a detailed proof, see Appendix C.

[14] From (6) and using the above parameter values, we have $G \equiv \frac{k}{\rho_S(1+t)} = 19.05$.

model validity dictates that the discount rates cannot be too low, they do not have a natural upper limit. Theoretically that means that the area of admissible discount rates is infinitely large, and hence that the probability that the complete-information solution is incentive compatible, is negligible – if all discount rates between $\max\{P/\varphi, \gamma/G\}$ and ∞ are deemed equally likely. To get a measure of how likely it is that the complete-information solution is incentive-compatible, we assume that $\rho_P, \rho_I \leq \overline{\rho}$, where $\overline{\rho}$ is the maximum "plausible" discount rate. Figure 2 is drawn assuming that $\overline{\rho}$ = 0.20.

Within the area demarcated by $\rho_P > 0.073$, $\rho_I > \rho_P$ and $\rho_P, \rho_I \leq 0.20$, the combination of (ρ_P, ρ_I) for which the complete information solution is incentive compatible, is indicated by the shaded rectangle in Figure 3. The eastern boundary of this region reflects the patient farmers' critical discount rate for which the left-hand side of (15) holds with strict equality. In other words, it is the critical discount rate for which $b_P^{*F} = \tilde{b}$ (for higher discount rates b_P^{*F} is to the left of $\tilde{b}$ in Figure 1). Similarly, the southern boundary is determined by the impatient farmers' critical discount rate for which the right-hand side of (15) holds with strict equality (for lower discount rates b_I^{*F} is to the right of $\tilde{b}$ in Figure 1). Given the parameter values chosen, we find that in the area for which all necessary conditions in the model hold, the complete information solution is incentive compatible for about 40% of all possible time preference combinations.

4 Optimal conservation when land quality is endogenous

4.1 Land quality investment

Let us now analyze whether the complete information conservation program is still incentive compatible if land quality is not predetermined – that is, when farmers can adjust their land quality after they have been informed about the specifics of the menu of contracts $((S_P, b_P), (S_I, b_I))$.

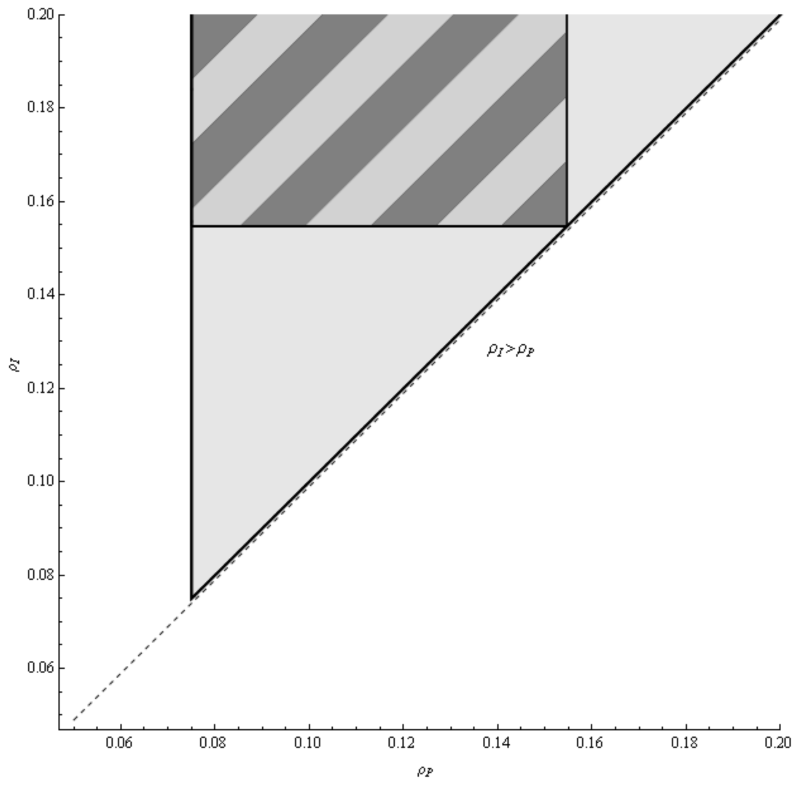

Figure 2: Range of time preference combinations that meets the model requirements (the grey triangle), and the range of time preference combinations for which the complete-information solution is incentive compatible (the shaded rectangle).

Using superscript E to denote this case in which farmers' land quality is endogenous (rather than predetermined), the farmer's profits (π_i^E) are equal to r_i^E (cf. (1)) minus c_i^E (cf. (2)). For given ρ_i and for every $b \geq 0$, farmer i's optimal investment level α_i^E can be derived by solving the following maximization problem:

$$\pi_i^E\left(b, \rho_i\right) = \max_{\alpha} \frac{P\alpha_i}{\rho_i} - \frac{\alpha_i^2}{2} - \frac{\gamma b}{\rho_i} - \frac{b^2}{2}(\varphi - \alpha_i). \tag{16}$$

Taking the first derivative of (16) with respect to α_i we obtain

$$\alpha_i^E(b, \rho_i) = \frac{P}{\rho_i} + \frac{b^2}{2}, \tag{17}$$

and hence

$$r_i^E(b,\rho_i) = \frac{P^2}{2\rho_i^2} - \frac{b^4}{8};\; c_i^E(b,\rho_i) = \frac{\gamma b}{\rho_i} + \frac{b^2}{2}\left(\varphi - \left(\frac{P}{\rho_i} + \frac{b^2}{2}\right)\right). \tag{18}$$

That means that for given $b \geq 0$, the profits of farmers of type i are equal to

$$\pi_i^E(b,\rho_i) = \frac{P^2}{2\rho_i^2} - \frac{b^4}{8} - \frac{\gamma b}{\rho_i} - \frac{b^2}{2}\left(\varphi - \left(\frac{P}{\rho_i} + \frac{b^2}{2}\right)\right). \tag{19}$$

Note that if a farmer of type i decides not to participate in the conservation program, her privately optimal value of b is equal to zero, so that $\alpha_i^E(0,\rho_i) = P/\rho_i$ and $\pi_i^0 = \pi_i^E(0,\rho_i) = 0.5P^2/\rho_i^2$; cf. (7). For whatever level b_i required, the returns to participation $\left(S_i + \pi_i^E(\rho_i, b_i)\right)$ should not be smaller than the returns to 'opting out' (π_i^0). Inserting (19) into (3), the participation constraints in case land quality is endogenous can be written as follows:

$$S_i \geq \pi_i^0 - \pi_i^E(b_i,\rho_i) = \frac{\gamma b_i}{\rho_i} + \frac{\varphi b_i^2}{2} - \frac{P b_i^2}{2\rho_i} - \frac{b_i^4}{8}. \tag{20}$$

We follow the same strategy as in section 3. In section 4.2 we first derive the optimal solution of the government's maximization problem under complete information (that is, when incentive compatibility is not an issue), and in section 4.3 we analyze under what circumstances the complete information solution is incentive compatible in the presence of information asymmetries.

4.2 The complete information solution

Absent information asymmetries, the government would choose a menu of contracts, (S_P, b_P) and (S_I, b_I), to maximize social welfare (4), taking into account the farmers' participation constraints (20), and also farmers' investments in land quality (α_P and α_I) in response to the conservation levels (b_P, b_I) set by the government.[15] The menu of contracts that solves the government's maximization problem under complete information is given in Proposition 4.

Proposition 4 *The complete information menu of conservation levels and subsidies when land quality is endogenous,* (S_I^{*E}, b_I^{*E}) *and* (S_P^{*E}, b_P^{*E})*, is given implicitly by:*

$$G - \frac{\gamma}{\rho_i} - \left(\varphi - \frac{P}{\rho_i}\right) b_i^{*E} = -\frac{(b_i^{*E})^3}{2}, \tag{21}$$

$$S_i^{*E} = \frac{\gamma b_i^{*E}}{\rho_i} + \frac{\varphi (b_i^{*E})^2}{2} - \frac{P(b_i^{*E})^2}{2\rho_i} - \frac{(b_i^{*E})^4}{8}. \tag{22}$$

Proof: see Appendix E. ■

Compared to the case where the investment decision is determined prior to government initiating a conservation program, we have $b_i^{*E} > b_i^{*F}$ for $i = \{P, I\}$.[16] The intuition is straightforward. Farmers take into account the fact that investments in land quality reduce the up-front investments needed to be able to provide conservation services. Hence, for every level of conservation effort b, these up-front conservation investment costs are smaller compared to the case when land quality is predetermined, and hence the socially optimal amount of conservation services is larger.

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[15]More precisely, the complete information menu of conservation contracts in this case should specify the required land quality investments (α_i^{*E}), per period conservation efforts (b_i^{*E}) and subsidies received (S_i^{*E}) by the different farmers' types. However, in our setting, this extended contract is equivalent to the one that specifies the conservation efforts and compensation payments only, since farmers choose the same land quality levels as the government would impose if it would possess the information to be able to do so. Indeed, given b, farmers have an incentive to choose α to maximize their profits. That means that they thus decrease the amount of compensation needed, and therefore the objectives of the farmers and the government are perfectly aligned in this respect. As a result, the case where land quality is not observable (and hence the government is unable to contract on land quality) does not result in moral hazard issues exacerbating the adverse selection problem. The formal details can be found in Appendix E.

[16]This is because the LHS of (21) is the first-order condition of problem (4) when the investments in land quality are predetermined. That means that when $b_i = b_i^{*F}$, the LHS of (21) is zero while the RHS is unambiguously negative (cf. (11)). To have equality, the LHS must be negative, and because $\varphi > P/\rho_i$ for all i (cf. (9)), we have $b_i^{*E} > b_i^{*F}$.

Cost function (2) assumes $\varphi > \alpha_i^{*E}$ for all i; using (17) and because $\rho_I > \rho_P$, this boils down to

$$\varphi > \frac{P}{\rho_P} + 0.5(b_P^{*E})^2. \tag{23}$$

Note that this condition is more restrictive than the one we have when land quality is predetermined (in that case, we have $\varphi > P/\rho_P$, see (9)). Since $b_P^{*E} > b_P^{*F} > 0$, (9) is always met if (23) holds. Furthermore, combining (23) and (6) implies that a necessary condition for the model to be valid in this second scenario is that

$$\rho_P > \max\left\{\frac{P}{\varphi - 0.5(b_P^{*E})^2}, \frac{\gamma}{G}\right\}, \tag{24}$$

where b_P^{*E} is implicitly defined in (21).

4.3 Is $(S_I^{*E}, b_I^{*E}), (S_P^{*E}, b_P^{*E})$ ever incentive compatible?

Inserting (19) into (5) and cancelling terms, the incentive compatibility condition for farmer type i ($i, j = \{P, I\}; j \neq i$) now becomes:

$$S_i^{*E} - \frac{\gamma b_i^{*E}}{\rho_i} - \frac{\varphi(b_i^{*E})^2}{2} + \frac{P(b_i^{*E})^2}{2\rho_i} + \frac{(b_i^{*E})^4}{8} \geq S_j^{*E} - \frac{\gamma b_j^{*E}}{\rho_i} - \frac{\varphi(b_j^{*E})^2}{2} + \frac{P(b_j^{*E})^2}{2\rho_i} + \frac{(b_j^{*E})^4}{8}. \tag{25}$$

Substituting (22) into (25), we obtain the following result.

Proposition 5 *The complete information conservation program,* (S_P^{*E}, b_P^{*E}) *and* (S_I^{*E}, b_I^{*E})*, is incentive compatible if and only if:*

$$b_I^{*E} \leq \frac{2\gamma}{P} \leq b_P^{*E}. \tag{26}$$

Proof: see Appendix G. ■

Surprisingly, we find that the required range for the complete information solution to be incentive compatible is equal to $b_I^{*s} \leq 2\gamma/P \leq b_P^{*s}$, $s = \{F, E\}$ – compare Propositions 2 and 5. Expressed in terms of conservation effort levels, the requirement is thus independent of whether land quality investments are endogenous at the time the program is announced, or whether they are predetermined; cf. (14) and (26). The reason for this is technical and not robust to the way in which the cost and revenue functions were specified. Comparing (7) and (17) we have $\alpha_i^{*E}(b,\rho_i) > \alpha_i^F(\rho_i)$. Land quality is higher when it can be adjusted after the program is introduced because it reduces the up-front costs of conservation. However, the increase in land quality investment is equally large for both farmer types: $\alpha_P^{*E}(b,\rho_P) - \alpha_P^F(\rho_P) = \alpha_I^{*E}(b,\rho_I) - \alpha_I^F(\rho_I)$; cf. (7) and (17). In Figure 1, this implies that the cost functions of the patient and impatient types shift down by the same distance. As a consequence, the cost functions for the two farmer types intersect at exactly the same conservation level ($\tilde{b}$) as in the case farmers move first.[17]

Even though (26) and (14) are identical, the set of parameter values for which the complete information program is incentive compatible is different compared to when farmers move first. We state the result in the following proposition.

Proposition 6 *The complete information solution,* (S_I^{*E}, b_I^{*E}) *and* (S_P^{*E}, b_P^{*E})*, is incentive compatible if and only if*

$$\rho_P \leq \frac{P^3\gamma}{2\gamma P^2\varphi - GP^3 - 4\gamma^3} \leq \rho_I. \tag{27}$$

Proof. Using (21), let us define $V(b_i^{*E},\rho_i) \equiv G - \frac{\gamma}{\rho_i} - \left(\varphi - \frac{P}{\rho_i}\right) b_i^{*E} + 0.5(b_i^{*E})^3$. Equation (26) states that $b_I^{*E} \leq 2\gamma/P$, which requires that $V(2\gamma/P,\rho_I) \leq 0$. Solving, we have $G \leq$

[17] As was the case in section 3, the non-trivial intersection point of the cost functions does not depend on the farmers' actual discount rates, and hence this model does not generalize to more than two farmer types. However, the more general revenue function presented in footnote 6 again results in $\tilde{b}_{ij}$ becoming a function of ρ_i and ρ_j, and hence the incentive compatibility results then generalize to the case of having three or more farmer types. For details, see Appendix H.

$\gamma\left(\frac{2\varphi}{P}-\frac{1}{\rho_I}\right)-\frac{4\gamma^3}{P^3}$, and hence $\frac{P^3\gamma}{2\gamma P^2\varphi-GP^3-4\gamma^3} \leq \rho_I$. Similarly, $b_P^{*E} \geq 2\gamma/P$ requires that $V(2\gamma/P, \rho_P) \geq 0$, which yields $\rho_P \leq \frac{P^3\gamma}{2\gamma P^2\varphi-GP^3-4\gamma^3}$.■

We thus find that when land investments are endogenous, the complete information solution can be incentive compatible even if each individual farmer's rate of time preference is unobservable to the regulator.[18] Compared to the exogenous land quality scenario, the conservation cost functions depicted in Figure 1 shift down. Larger investments in land quality implies that the costs of conservation are smaller in the endogenous case, and the associated marginal conservation costs are then also lower for every level of b. That means that for any value of, for example, the marginal environmental benefits of conservation policy, k, the complete-information conservation levels are higher when land quality is endogenous than when it is predetermined. While a specific level of k may yield $\tilde{b} > b_I^{*F} > b_P^{*F}$(that is, a second-best solution, see also Appendix D), that same k may result in the complete information conservation levels ending up on either side of $\tilde{b}$ when land quality is endogenous. But it also means that while a higher level of k causes the complete information solution to be incentive compatible when land quality is predetermined (as in Figure 1), that same level of k may yield $\tilde{b} < b_I^{*E} < b_P^{*E}$ when land quality is endogenous.

5 Empirical validity of the key assumptions

For our model to be valid, we need to establish the empirical validity of three key assumptions. First, more patient farmers should not have better or worse access to credit than more impatient ones. Second, the propensity to invest in maintaining the quality of their soils should be decreasing in the farmers' rate of time preference, and better maintained and protected soils

[18]For a formal proof of the second-best solution when land investments are endogenous, see Appendix I.

should translate into higher per-period profits. Third, nature conservation should be less costly to establish on lands with better preserved and maintained soils.

The third relationship is quite straightforward, and ample research indicates that this is indeed the case. For example, Asefa et al. (2002) report that biodiversity restoration in Ethiopia is more costly on more degraded lands, and Lal (2004) offers similar insights regarding the costs of restoring CO2 sequestration capacity on degraded lands. To assess the empirical validity of the first two relationships, we use data collected by Tesfaye and Brouwer (2012) who tried to identify what drives farmers' investments in soil conservation structures in an arid region in Ethiopia. They did so by means of a choice experiment among a representative sample of 750 farmers, some of whom already voluntarily invested in such structures in the past, while others did not. To estimate the effectiveness of a new policy program targeted at inducing investments, respondents were offered a range of contracts that differed in a variety of attributes including the type of conservation measure to be adopted within the program, the length of the contract, and the monthly payment. We are interested in analyzing (selection in) past investment decisions, and hence our focus is primarily on observables like past investments in conservation structures and other household characteristics such as income; we only use the choice experimental outcomes to infer differences in the rates of time preferences.

Although Tesfaye and Brouwer did not explicitly elicit the respondents' rate of time preference, we can infer them by scoring how often in the choice experiment a farmer chose the contract with the shortest duration. The more often a farmer chooses the shortest contract – all else equal – the more impatient he presumably is. While this does not allow us to actually measure each farmer's implicit rate of time preference, it does provide us with a metric of impatience along which farmers can be ranked. We now report the evidence supporting the real-world relevance of the first two relationships.

Regarding unequal access to credit, the first key issue identified above, the data by Tesfaye and Brouwer (2012) indicate that only slightly more than 19% of the respondents has access to credit. The average farmer is thus not likely to have access to credit, but then some may have better access than others. We test this by means of a straightforward probit analysis of the determinants of farmer access to credit. We use the following specification:

$$AccessCredit_i = c_0 + c_1 \textit{ImpatienceMetric}_i + c_2 Z_i + \varepsilon_i, \tag{28}$$

where $AccesCredit_i$ is a binary variable indicating whether farmer i has access to credit, or not, $ImpatienceMetric_i$ is the variable that allows us to rank farmers from very patient (low value) to very impatient (high value), and Z_i is a vector of household characteristics including the household head's age (age itself but also the squared value of age) and gender, and also potentially endogenous variables like household agricultural income and the size of its land. In addition, we also include region fixed effects.

The results of the analysis are presented in Table 1. We find that our metric of impatience never shows up significantly – as the p-value of the coefficient on the implicit rate of time preference is never below 0.900. Hence, the data do not allow us to reject the hypothesis that access to credit is uncorrelated with farmers' rate of time preference.

Table 1: Determinants of access to credit.[a]

	(1)	(2)
Impatience metric	0.00409	0.199
	(0.30)	(0.30)
Gender	0.343	0.338
	(0.24)	(0.25)
Age	0.0481*	0.0466*
	(0.03)	(0.03)
Age squared	-0.0005*	-0.0005*
	(0.00)	(0.00)
Income		-0.00000761
		(0.00)
Landsize		0.164
		(0.12)
Constant	-2.178***	-2.100***
	(0.66)	(0.70)
N	750	721
Wald χ^2	13.97	19.64

[a] Robust standard errors in parentheses; * $p<0.10$ ** $p<0.05$ *** $p<0.01$.

Finally, the second key relationship identified above, the one between soil maintenance investments and profits (income), is not very straightforward to establish. Farmers are credit-constrained, and hence soil quality investments are not only likely to raise income – farmers with higher income levels are also more likely to be able to invest in soil conservation structures. Because of these reasons we estimate a three stage least squares model, where we allow the rate of time preference and (the log of) income to affect whether farmers undertook soil conservation measures, and we also test whether the decision to invest in soil conservation measures affects the income flow. This gives rise to the following two-equation regression model, using location fixed effects and farmer characteristics (gender, age, land area, and literacy) to identify the two relationships:

$$\ln Income_i = b_0 + b_1 SoilConsMeas_i + b_2 Y_i + \zeta_i, \tag{29}$$

$$SoilConsMeas_i = c_0 + c_1 \ln Income_i + c_2 \textit{ImpatienceMetric}_i + c_3 Z_i + \eta_i, \tag{30}$$

Here, $SoilConsMeas_i$ is a binary variable indicating whether farmer i has implemented soil conservation measures on his land, Y_i is a vector of household-specific characteristics including the household head's gender, age, and the size of his/her land, and Z_i is a vector including age, illiteracy and region fixed effects.[19]

The results are presented in Table 2.

Table 2: Income, soil conservation measures and the farmer's rate of time preference.[a]

Dependent variable:	SoilConsMeas		lnIncome
lnIncome	0.186**	Soilconsmeas	0.0854*
	(0.08)		(0.52)
ImpatienceMetric	-0.129*	Gender	-0.0376
	(0.08)		(0.09)
Age	0.00461***	Age	-0.00850***
	(0.00)		(0.00)
Literacy	-0.0870**	Landsize	0.160**
	(0.03)		(0.07)
Constant	-1.096	Constant	8.758***
	(0.74)		(0.30)
N	721	N	721
Wald χ^2	27.62**	Wald χ^2	62.98***

[a] Robust standard errors in parentheses; * $p<0.10$ ** $p<0.05$ *** $p<0.01$.

[19]Hence, income equation is identified by gender and landsize, and the soil conservation measure's equation is identified by the impatience metric and by illiteracy. Also note that we include location fixed effects in equation (30), but not in equation (29). When including them in equation (29) they do not show up significantly, and they also do not appreciatively affect the results (neither qualitatively nor quantitatively). Because the region dummies facilitate identification of equation (30), we report the results of the model where the location fixed effects are included in equation (30) but not in equation (29).

The results are in line with the hypothesized relationship. First, farmers with higher incomes are more likely to invest in soil conservation structures, but more importantly, they are less inclined to do so the more impatient they are – as measured by our metric of farmers' rates of time preference (with $p = 0.035$). This is the case when conditioning the relationship on education – all else equal, illiterate farmers are less likely to invest. Having controlled for the potential reverse causality of income on investments, we find that soil conservation structures do raise income (albeit at $p = 0.086$ only).

6 Conclusions

In this paper we extend the literature on optimal environmental subsidy programs in the presence of information asymmetries. The extant literature typically assumes that the costs of supplying environmental services differ between agents because their production (or consumption) technologies differ – agents are assumed identical in all other respects. These assumptions do not seem very plausible because they imply that it is essentially random which agent owns what technology – rather than that ownership is the outcome of the agent's decision making process. We show that if technology choice is endogenously determined by agents who differ in a truly unmalleable characteristic, like their rate of time preference, the complete-information solution can be incentive compatible even in the presence of information asymmetries. The reason is that differences in preferences imply that agents differ in multiple respects: not just with respect to the costs of environmental services provided because of the technology they own, but also with respect to how they value a specific flow of benefits and costs over time. The consequence is that some agents can supply environmental services at lower costs than others for some service levels, while the reverse holds for other levels of service provision – in other words, the cost functions of the two types intersect. We show that the complete information solution can be incentive compatible if agents' production technologies (in our example, land) is predetermined at the moment the environmental policy is introduced, but also when the agents can revise their technology decisions (i.e., adjust their land qualities) in response to the program being introduced.

The purpose of this paper is to draw attention to the fact that the typical conclusion of the adverse selection literature – that the complete information solution is never incentive compatible – may not hold in a world where most contexts and circumstances are malleable. We focus on land quality, arguing that land quality is ultimately endogenous and the outcome of a decision-making process that may be affected by many different factors – including the land owner's time preferences. Ultimately, and because of a lack of empirical evidence, this is just an example of how selection can result in the complete information being incentive compatible. Indeed, we believe that the insights obtained in this paper are sufficiently general that they apply for many other environmental subsidy programs too.

The reader may argue that our result is a theoretical nicety with only limited empirical relevance. Indeed, as can be inferred from our analysis, the chances of the complete information being incentive compatible is smaller the larger is the number of different types there are with respect to a specific characteristic – extending the model from two to multiple levels of (im)patience shrinks the range of parameters for which the complete information solution is incentive compatible. Rather than viewing this as a sign that incentive compatible contracts cannot deliver in practice what they promise to offer in theory, we see this as a stimulus to start thinking about optimal 'bunching' and/or exclusion of types – starting with n types distributed over a specific support, can we construct a menu of $m < n$ contracts that approximates the complete information solution?[20] This is especially important because this paper also suggest that the probability of the complete-information solution being incentive compatible is larger the larger the number of different characteristics agents have (think of risk preferences resulting in farmers choosing a specific land quality or a specific type of crop, in addition to their rates of time preferences – assuming that the two types of preferences are not perfectly correlated). Empirical evidence on the relationship between agents' preferences (elicited for example via incentive-compatible economic experiments) and (truthfully revealed) required compensation levels (think of data generated from a uniform price procurement auction) is needed to see whether this paper's idea remains theory, or whether its insights can be applied in practice.

7 Appendix

A. Proof of Proposition 1. The Lagrangian of the government's optimization problem (4) including the incentive compatibility constraints is the following:

$$\begin{aligned} L \;=\; & \sum\nolimits_{i\in\{P,I\}} \frac{q_i b_i k}{\rho_S} + \sum\nolimits_{i\in\{P,I\}} q_i \left[\frac{P^2}{2\rho_i^2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \alpha_i^F)\right] \\ & - t\sum\nolimits_{i\in\{P,I\}} q_i S_i + \sum\nolimits_{i\in\{P,I\}} \lambda_i \left[S_i - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}\left(\varphi - \alpha_i^F\right)\right] \\ & + \sum\nolimits_{i\in\{P,I\}} \mu_i \left[S_i - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \alpha_i^F) - S_{-i} + \frac{\gamma b_{-i}}{\rho_i} + \frac{b_{-i}^2}{2}(\varphi - \alpha_i^F)\right], \end{aligned} \tag{31}$$

where $\lambda_i \geq 0$ is the Kuhn–Tucker multiplier associated with type i's participation constraint; cf. (8), and $\mu_i \geq 0$ is the multiplier associated with the incentive compatibility constraint of

[20] Bunching is typically stated as a solution to asymmetric information problems when heterogeneity is multi-dimensional. In fact, it is often claimed that bunching and/or the exclusion of some agents at the optimum is a generic property in multidimensional problems (Armstrong and Rochet 1999, Rochet and Choné 1998, Armstrong 1996, Laffont et al. 1987, and Salanié 2005, pp. 78-82).

type $i = P, I$. The corresponding Kuhn–Tucker conditions are:

$$\begin{aligned}
\frac{\partial L}{\partial b_P} &= \frac{q_P k}{\rho_S} - (q_P + \lambda_P)\left(\frac{\gamma}{\rho_P} + b_P(\varphi - \alpha_P^F)\right) - \mu_P\left(\frac{\gamma}{\rho_P} + b_P(\varphi - \alpha_P^F)\right) \\
&\quad + \mu_I\left(\frac{\gamma}{\rho_I} + b_P(\varphi - \alpha_I^F)\right) = 0\ , && (32) \\
\frac{\partial L}{\partial b_I} &= \frac{q_I k}{\rho_S} - (q_I + \lambda_I)\left(\frac{\gamma}{\rho_I} + b_I(\varphi - \alpha_I^F)\right) + \mu_P\left(\frac{\gamma}{\rho_P} + b_I(\varphi - \alpha_P^F)\right) \\
&\quad - \mu_I\left(\frac{\gamma}{\rho_I} + b_I(\varphi - \alpha_I^F)\right) = 0, && (33) \\
\frac{\partial L}{\partial S_P} &= -tq_P + \lambda_P + \mu_P - \mu_I = 0, && (34) \\
\frac{\partial L}{\partial S_I} &= -tq_I + \lambda_I - \mu_P + \mu_I = 0, && (35)
\end{aligned}$$

$$\begin{aligned}
&\lambda_P \quad \left[S_P - \frac{\gamma b_P}{\rho_P} - \frac{b_P^2}{2}(\varphi - \alpha_P^F)\right] = 0;\ \lambda_P \geq 0; \\
&S_P \quad - \frac{\gamma b_P}{\rho_P} - \frac{b_P^2}{2}(\varphi - \alpha_P^F) \geq 0, && (36) \\
&\lambda_I \quad \left[S_I - \frac{\gamma b_I}{\rho_I} - \frac{b_I^2}{2}(\varphi - \alpha_I^F)\right] = 0;\ \lambda_I \geq 0; \\
&S_I \quad - \frac{\gamma b_I}{\rho_I} - \frac{b_I^2}{2}(\varphi - \alpha_I^F) \geq 0, && (37) \\
&\mu_P \quad \left[S_P - \frac{\gamma b_P}{\rho_P} - \frac{b_P^2}{2}(\varphi - \alpha_P^F) - S_I + \frac{\gamma b_I}{\rho_P} + \frac{b_I^2}{2}(\varphi - \alpha_P^F)\right] = 0; \\
&\quad \mu_P \geq 0;\ S_P - \frac{\gamma b_P}{\rho_P} - \frac{b_P^2}{2}(\varphi - \alpha_P^F) - S_I + \frac{\gamma b_I}{\rho_P} + \frac{b_I^2}{2}(\varphi - \alpha_P^F) \geq 0, && (38) \\
&\mu_I \quad \left[S_I - \frac{\gamma b_I}{\rho_I} - \frac{b_I^2}{2}(\varphi - \alpha_I^F) - S_P + \frac{\gamma b_P}{\rho_I} + \frac{b_P^2}{2}(\varphi - \alpha_I^F)\right] = 0; \\
&\quad \mu_I \geq 0;\ S_I - \frac{\gamma b_I}{\rho_I} - \frac{b_I^2}{2}(\varphi - \alpha_I^F) - S_P + \frac{\gamma b_P}{\rho_I} + \frac{b_P^2}{2}(\varphi - \alpha_I^F) \geq 0. && (39)
\end{aligned}$$

In the complete information case, we can ignore Kuhn-Tucker conditions (38) and (39) and set $\mu_P = \mu_I = 0$ in (32)–(37). Now, (34) and (35) imply that $\lambda_i = tq_i > 0$ so that $S_i^{*F} = \gamma b_i^{*F}/\rho_i + \left(b_i^{*F}\right)^2 (\varphi - \alpha_i^F)/2$ (see (36) and (37)). Next, substituting (34), (35) and (7) into (32) and (33), we have $b_i^{*F} = \frac{1}{\rho_i}\left(\frac{\rho_i G - \gamma}{\varphi - \alpha_i^F}\right)$ where $G \equiv k/\rho_S(1+t)$; cf. (6).

B. Proof of Proposition 2. The complete information solution can be implemented if $\mu_P = \mu_I = 0$ does not yield a contradiction in (32)–(39). Note that if $\mu_P = \mu_I = 0$ it holds that $\lambda_i = tq_i > 0$, and thus $S_i^{*F} = \frac{\gamma b_i^{*F}}{\rho_i} + \frac{\left(b_i^{*F}\right)^2}{2}(\varphi - \alpha_i^F)$ for $i = P, I$ which does not yield a contradiction in (32)–(39). Hence, inserting (12) into (13) and dividing by b_j^{*F}, we have

$$0 \geq \frac{\gamma}{\rho_j} + \frac{b_j^{*F}}{2}(\varphi - \alpha_j^F) - \frac{\gamma}{\rho_i} - \frac{b_j^{*F}}{2}(\varphi - \alpha_i^F) \tag{40}$$

Substituting and $\alpha_i^F = P/\rho_i$ into (40) and rewriting, we have

$$\frac{\gamma}{\rho_i} - \frac{\gamma}{\rho_j} \geq \frac{b_j^{*F}}{2}(\frac{P}{\rho_i} - \frac{P}{\rho_j}) \tag{41}$$

Substituting in $i, j = \{I, P\}$ and $j \neq i$, we have

$$b_I^{*F} \leq \frac{2\gamma}{P} \leq b_P^{*F}. \tag{42}$$

C. Incentive compatibility of the complete information solution when there are more than two farmer types and when land quality is predetermined. Assume that the profits of farmers of type i are given by $\pi_i^N(b_i, \alpha_i, \rho_i) = \frac{P\alpha_i(1-b_i)}{\rho_i} - \frac{\alpha_i^2}{2} - \frac{b_i^2}{2}(\varphi - \alpha_i) - \frac{\gamma b_i}{\rho_i}$; see footnote 7. Farmers choose land quality before the conservation program is anounced, and hence they all choose $b = 0$. Then $\alpha_i = \alpha_i^F = P/\rho_i$. A necessary condition for the problem to be non-trivial is that the discounted marginal social benefits of conservation (taking into account the costs of raising funds), $G \equiv (\rho_S(1+t))^{-1}k$, are larger than the discounted value of the first unit of conservation costs incurred: $\partial\pi_i^N/\partial b_i\big|_{b_i=0} = P^2/\rho_i^2 + \gamma/\rho_i$. Hence, conservation activities by farmer i are socially desired only if $G \equiv \frac{k}{\rho_S(1+t)} > \frac{P^2}{\rho_i^2} + \frac{\gamma}{\rho_i}$ holds, or rewriting terms:

$$\rho_i > \frac{\gamma + \sqrt{\gamma^2 + 4GP^2}}{2G} = \bar{\rho}. \tag{43}$$

So, the government should design a program such that all farmers with $\rho_i > \bar{\rho}$ are willing to participate. Let us assume there are Z types of farmers with $\rho_1 > \rho_2 > \ldots > \rho_n > \bar{\rho} >$

$\rho_{n+1} > \ldots > \rho_Z$ (ordered from least to most patient). From a societal point of view, all farmers of type $\{1, 2, \ldots, n\}$ should participate in the program, and those of type $\{n+1, ..., Z\}$ should not participate.

Now, the Lagrangian of the government's optimization problem (4) can be written as:

$$\begin{aligned} L \;=\; & \sum\nolimits_{i\in\{1,2,\ldots,n\}} \frac{q_i b_i k}{\rho_S} + \sum\nolimits_{i\in\{1,2,\ldots,n\}} q_i \left[\frac{P^2}{2\rho_i^2} - \frac{P^2 b_i}{\rho_i^2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \frac{P}{\rho_i})\right] \\ & -t \sum\nolimits_{i\in\{1,2,\ldots,n\}} q_i S_i + \sum\nolimits_{i\in\{1,2,\ldots,n\}} \lambda_i \left[S_i - \frac{P^2 b_i}{\rho_i^2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \frac{P}{\rho_i})\right] \\ & + \sum\nolimits_{i\in\{1,2,\ldots,n\}} \sum\nolimits_{j\in\{1,2,\ldots,n\}\setminus\{i\}} \mu_{ij} \left[S_i - \frac{P^2 b_i}{\rho_i^2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \frac{P}{\rho_i}) - S_j + \frac{P^2 b_j}{\rho_i^2}\right. \\ & \left. + \frac{\gamma b_j}{\rho_i} + \frac{b_j^2}{2}(\varphi - \frac{P}{\rho_i})\right], \end{aligned} \tag{44}$$

where $\lambda_i \geq 0$ is the Kuhn–Tucker multiplier associated with type i's participation constraint, and $\mu_{ij} \geq 0$ is the multiplier associated with the incentive compatibility constraint of type $i, j = \{1, 2, \ldots, n\}, j \neq i$. Solving the corresponding Kuhn–Tucker conditions, we have $b_i^{*N} = \frac{1}{\rho_i}\left(\frac{\rho_i^2 G - \rho_i\gamma - P^2}{\rho_i\varphi - P}\right)$ and $S_i^{*N} = \frac{\gamma b_i^{*N}}{\rho_i} + \frac{\left(b_i^{*N}\right)^2}{2\rho_i}(\rho_i\varphi - P) + \frac{P^2 b_i^{*N}}{\rho_i^2}$ as the complete information menu of conservation levels and subsidies when land quality is predetermined.

To find when this solution is incentive compatible, we solve $\mu_{ij} = 0$ for all $i, j = \{1, 2, \ldots, n\}, j \neq i$. This yields $\lambda_i = tq_i > 0$, and thus $S_i^{*N} = \frac{\gamma b_i^{*N}}{\rho_i} + \frac{\left(b_i^{*N}\right)^2}{2\rho_i}(\rho_i\varphi - P) + \frac{P^2 b_i^{*N}}{\rho_i^2}$. Substituting S_i^{*N} and π_i^N in (5) and cancelling terms, we find that the complete information solution is incentive compatible if and only if, for all $\{j, i\}$, $j < i$, we have $b_i^{*N} \leq \tilde{b}_{ij}^N(\rho_i, \rho_j) \leq b_j^{*N}$ with $\tilde{b}_{ij}^N(\rho_i, \rho_j) = \frac{2\gamma}{P} + 2P\left(\frac{1}{\rho_i} + \frac{1}{\rho_j}\right)$.

Note that if $j < i$, we have $\rho_j > \rho_i$ due to the ordering of types. Now, let us define $v_{ij} \equiv \rho_j - \rho_i$. Then we have $\tilde{b}_{ij}^N(\rho_i, \rho_j) = \frac{2\gamma}{P} + 2P\left(\frac{1}{\rho_i} + \frac{1}{\rho_i + v_{ij}}\right)$, and $\partial\tilde{b}_{ij}^N(\rho_i, \rho_j)/\partial\rho_i = -2P\left(\frac{1}{\rho_i^2} + \frac{1}{(\rho_i + v_{ij})^2}\right) < 0$. Hence, the intersection point of the cost functions for farmers i and j is closer to the origin the more impatient the reference farmer type is. Having established the type-specific intersection point, a necessary condition for $b_i^{*N} \leq \tilde{b}_{ij}^N(\rho_i, \rho_j) \leq b_j^{*N}$ to be non-empty is that $\partial b_i^{*N}/\partial \rho_i < 0$.

D. Derivation of the second-best solutions when land quality is predetermined. We first derive the second-best policy when $b_I^{*F} > 2\gamma/P$. The complete information solution with $\mu_P = \mu_I = 0$ cannot be implemented because $\mu_P = 0$ now yields a contradiction in (38), which leaves us with the possibility that $\mu_P > 0$ and $\mu_I = 0$. Now, (35) reads $\lambda_I = \mu_I + tq_I > 0$, so $\lambda_P \geq 0$ and $\lambda_I > 0$. Now, $\lambda_P > 0$ and $\lambda_I > 0$ would imply that $S_i = \frac{\gamma b_i}{\rho_i} + \frac{b_i^2}{2}(\varphi - \alpha_i^F)$ with $i = P, I$; see (36) and (37). However, since $\mu_P > 0$ this implies that $S_P - \frac{\gamma b_P}{\rho_P} - \frac{b_P^2}{2}(\varphi - \alpha_P^F) - S_I + \frac{\gamma b_I}{\rho_P} + \frac{b_I^2}{2}(\varphi - \alpha_P^F) = 0$. Substituting $S_i = \frac{\gamma b_i}{\rho_i} + \frac{b_i^2}{2}(\varphi - \alpha_i^F)$ and $\alpha_i^F = \frac{P}{\rho_i}$ (with $i = P, I$) in the latter, and rearranging terms, yields $b_I = \frac{2\gamma}{P}$. This contradicts $b_I^{*F} > \frac{2\gamma}{P}$. Hence, if $\mu_P > 0$ and $\mu_I = 0$ it needs to hold that $\lambda_P = 0$ and $\lambda_I > 0$. In this case the second-best solution is characterized by the conditions:

$$\frac{\gamma}{\rho_P} + b_P(\varphi - \alpha_P^F) = G, \tag{45}$$

$$\frac{\gamma}{\rho_I} + b_I(\varphi - \alpha_I^F) = G - \frac{t}{1+t}\frac{q_P}{q_I}(b_I P - \gamma)(\frac{1}{\rho_P} - \frac{1}{\rho_I}) < G, \tag{46}$$

$$S_P - \frac{\gamma b_P}{\rho_P} - \frac{b_P^2}{2}(\varphi - \alpha_P^F) = S_I - \frac{\gamma b_I}{\rho_P} - \frac{b_I^2}{2}(\varphi - \alpha_P^F) > 0 \tag{47}$$

$$S_I - \frac{\gamma b_I}{\rho_I} - \frac{b_I^2}{2}(\varphi - \alpha_I^F) = 0. \tag{48}$$

The same analysis for $b_P^{*F} < \frac{2\gamma}{P}$ yields that the only feasible set of Kuhn-Tucker multipliers is $\mu_P = 0$, $\mu_I > 0$, $\lambda_P > 0$, and $\lambda_I = 0$. Hence, in this case the second-best solution is also characterized by (45)–(48) except that all subscripts P should now read I, and vice versa. (45) states that the amount of conservation provided by patient farmers should be such that the marginal costs of conservation equal the social marginal benefits of conservation. Note that since $b_I^{*F} > \frac{2\gamma}{P}$, $b_I P - \gamma > 0$ in (46). Hence, the amount of conservation that is provided by impatient farmers is smaller than the level that would equate marginal conservation cost to the social marginal benefits of conservation. Furthermore, (47) indicates that patient farmers should be indifferent between contracts, while (48) shows that impatient farmers receive compensation that is exactly equal to the conservation costs incurred. Hence, in this case, patient farmers receive informational rents for the conservation they provide, while impatient farmers provide less conservation than is socially desirable.

E. Proof of Proposition 4. The Lagrangian of the government's optimization problem (4) is the following:

$$\begin{aligned} L \;=\; & \sum\nolimits_{i\in\{P,I\}} \frac{q_i b_i k}{\rho_S} + \sum\nolimits_{i\in\{P,I\}} q_i \left[\frac{P^2}{2\rho_i^2} - \frac{b_i^4}{8} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}\left(\varphi - \frac{P}{\rho_i} - \frac{b_i^2}{2}\right)\right] \\ & -t\sum\nolimits_{i\in\{P,I\}} q_i S_i + \sum\nolimits_{i\in\{P,I\}} \lambda_i \left[S_i - \frac{\gamma b_i}{\rho_i} - \frac{\varphi b_i^2}{2} + \frac{P b_i^2}{2\rho_i} + \frac{b_i^4}{8}\right] \\ & + \sum\nolimits_{i\in\{P,I\}} \mu_i \left[S_i - \frac{\gamma b_i}{\rho_i} - \frac{\varphi {b_i}^2}{2} + \frac{P b_i^2}{2\rho_i} + \frac{{b_i}^4}{8}\right. \\ & \left. -S_{-i} + \frac{\gamma b_{-i}}{\rho_i} + \frac{\varphi {b_{-i}}^2}{2} - \frac{P {b_{-i}}^2}{2\rho_i} - \frac{{b_{-i}}^4}{8}\right], \end{aligned} \tag{49}$$

where $\lambda_i \geq 0$ Kuhn–Tucker multiplier associated with type i's participation constraint ($i = I, P$); cf. ((20)), and $\mu_i \geq 0$ is the multiplier associated with the incentive compatibility constraint of type $i = P, I$. The corresponding Kuhn–Tucker conditions are:

$$\begin{aligned} \frac{\partial L}{\partial b_P} =& \frac{q_P k}{\rho_S} - (q_P + \lambda_P)\left(\frac{\gamma}{\rho_P} + \left(\varphi - \frac{P}{\rho_P}\right) b_P - \frac{b_P^3}{2}\right) \\ & - \mu_P \left(\frac{\gamma}{\rho_P} + \left(\varphi - \frac{P}{\rho_P}\right) b_P - \frac{b_P^3}{2}\right) + \mu_I \left(\frac{\gamma}{\rho_I} + \left(\varphi - \frac{P}{\rho_I}\right) b_P - \frac{b_P^3}{2}\right) = 0, \end{aligned} \tag{50}$$

$$\begin{aligned} \frac{\partial L}{\partial b_I} =& \frac{q_I k}{\rho_S} - (q_I + \lambda_I)\left(\frac{\gamma}{\rho_I} + \left(\varphi - \frac{P}{\rho_I}\right) b_I - \frac{b_I^3}{2}\right) \\ & + \mu_P \left(\frac{\gamma}{\rho_P} + \left(\varphi - \frac{P}{\rho_P}\right) b_I - \frac{b_I^3}{2}\right) - \mu_I \left(\frac{\gamma}{\rho_I} + \left(\varphi - \frac{P}{\rho_I}\right) b_I - \frac{b_I^3}{2}\right) = 0, \end{aligned} \tag{51}$$

$$\frac{\partial L}{\partial S_P} = - t q_P + \lambda_P + \mu_P - \mu_I = 0, \tag{52}$$

$$\frac{\partial L}{\partial S_I} = - t q_I + \lambda_I - \mu_P + \mu_I = 0, \tag{53}$$

$$\lambda_P\left[S_P-\frac{\gamma b_P}{\rho_P}-\frac{\varphi b_P^2}{2}+\frac{Pb_P^2}{2\rho_P}+\frac{b_P^4}{8}\right]=0;$$

$$\lambda_P\geq 0; S_P-\frac{\gamma b_P}{\rho_P}-\frac{\varphi b_P^2}{2}+\frac{Pb_P^2}{2\rho_P}+\frac{b_P^4}{8}\geq 0, \tag{54}$$

$$\lambda_I\left[S_I-\frac{\gamma b_I}{\rho_I}-\frac{\varphi b_I^2}{2}+\frac{Pb_I^2}{2\rho_I}+\frac{b_I^4}{8}\right]=0;$$

$$\lambda_I\geq 0; S_I-\frac{\gamma b_I}{\rho_I}-\frac{\varphi b_I^2}{2}+\frac{Pb_I^2}{2\rho_I}+\frac{b_I^4}{8}\geq 0, \tag{55}$$

$$\mu_P\left[S_P-\frac{\gamma b_P}{\rho_P}-\frac{\varphi {b_P}^2}{2}+\frac{Pb_P^2}{2\rho_P}+\frac{{b_P}^4}{8}-S_I+\frac{\gamma b_I}{\rho_P}+\frac{\varphi {b_I}^2}{2}-\frac{P{b_I}^2}{2\rho_P}-\frac{{b_I}^4}{8}\right]=0;\ \mu_P\geq 0;$$

$$S_P-\frac{\gamma b_P}{\rho_P}-\frac{\varphi {b_P}^2}{2}+\frac{Pb_P^2}{2\rho_P}+\frac{{b_P}^4}{8}-S_I+\frac{\gamma b_I}{\rho_P}+\frac{\varphi {b_I}^2}{2}-\frac{P{b_I}^2}{2\rho_P}-\frac{{b_I}^4}{8}\geq 0, \tag{56}$$

$$\mu_I\left[S_I-\frac{\gamma b_I}{\rho_I}-\frac{\varphi {b_I}^2}{2}+\frac{Pb_I^2}{2\rho_I}+\frac{{b_I}^4}{8}-S_P+\frac{\gamma b_P}{\rho_I}+\frac{\varphi {b_P}^2}{2}-\frac{P{b_P}^2}{2\rho_I}-\frac{{b_P}^4}{8}\right]=0;\ \mu_I\geq 0;$$

$$S_I-\frac{\gamma b_I}{\rho_I}-\frac{\varphi {b_I}^2}{2}+\frac{Pb_I^2}{2\rho_I}+\frac{{b_I}^4}{8}-S_P+\frac{\gamma b_P}{\rho_I}+\frac{\varphi {b_P}^2}{2}-\frac{P{b_P}^2}{2\rho_I}-\frac{{b_P}^4}{8}\geq 0. \tag{57}$$

In the complete information case, we can ignore Kuhn-Tucker conditions (56) and (57) and set $\mu_P=\mu_I=0$. Now, (52) and (53) imply that $\lambda_i=tq_i>0$ so that $S_i^{*E}=\frac{\gamma b_i^{*E}}{\rho_i}+\frac{\varphi(b_i^{*E})^2}{2}-\frac{P(b_i^{*E})^2}{2\rho_i}-\frac{(b_i^{*E})^4}{8}$ (see (54) and (55)). Next, the optimal conservation level is implicitly defined by $G-\frac{\gamma}{\rho_i}-\left(\varphi-\frac{P}{\rho_i}\right)b_i^{*E}=-\frac{(b_i^{*E})^3}{2}$ where $G\equiv k/\rho_S(1+t)$, as desired.

F. Proof that Proposition 4 also holds when government contracts for conservation levels and investments in land quality. The problem the government solves in this case is the following:

$$\max_{b_i,\alpha_i,S_i}\quad W=\frac{k}{\rho_S}\sum\nolimits_{i\in\{P,I\}}q_ib_i+\sum\nolimits_{i\in\{P,I\}}q_i\pi_i(b_i,\alpha_i,\rho_i)-t\sum\nolimits_{i\in\{P,I\}}q_iS_i$$
$$s.t.\quad S_i\geq r(\alpha_i^O,\rho_i)-(r(\alpha_i,\rho_i)-c_i(b_i,\alpha_i,\rho_i))$$

The participation constraint states that when participating, farmers should be at least as well off as when opting out. That is:

$$S_i+r(\alpha_i,\rho_i)-c_i(b_i,\alpha_i,\rho_i)\geq\pi(\alpha_i^O,\rho_i)=r(\alpha_i^O,\rho_i)$$

Here, α_i^O is the land quality chosen by farmer i when he does not participate in the conservation program ($b_i = 0$). From (7) we know that $\alpha_i^O = P/\rho_i$. Using (16) and (20), we have

$$\pi_i(b_i, \alpha_i, \rho_i) = \frac{P\alpha_i}{\rho_i} - \frac{\alpha_i^2}{2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \alpha_i), \text{ and}$$
$$S_i + \frac{P\alpha_i}{\rho_i} - \frac{\alpha_i^2}{2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \alpha_i) \geq \pi_i^O\left(0, \alpha_i^O, \rho_i\right).$$

Hence the Lagrangian of the government's maximization problem reads as

$$\begin{aligned} L &= \sum\nolimits_{i\in\{P,I\}} \frac{q_i b_i k}{\rho_S} + \sum\nolimits_{i\in\{P,I\}} q_i \left(\frac{P\alpha_i}{\rho_i} - \frac{\alpha_i^2}{2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \alpha_i)\right) \\ &\quad -t\sum\nolimits_{i\in\{P,I\}} q_i S_i + \sum\nolimits_{i\in\{P,I\}} \lambda_i \left[S_i + \frac{P\alpha_i}{\rho_i} - \frac{\alpha_i^2}{2} - \frac{\gamma b_i}{\rho_i} - \frac{b_i^2}{2}(\varphi - \alpha_i) - \pi_i^O\left(0, \alpha_i^O, \rho_i\right)\right]. \end{aligned}$$

The first-order conditions with respect to b_i, α_i, and S_i are respectively given by

$$q_i \frac{k}{\rho_s} - q_i\left(\frac{\gamma}{\rho_i} + b_i(\varphi - \alpha_i)\right) - \lambda_i\left(\frac{\gamma}{\rho_i} + b_i(\varphi - \alpha_i)\right) = 0, \tag{58}$$
$$q_i\left(\frac{P}{\rho_i} - \alpha_i + \frac{b_i^2}{2}\right) + \lambda_i\left(\frac{P}{\rho_i} - \alpha_i + \frac{b_i^2}{2}\right) = 0, \tag{59}$$
$$-tq_i + \lambda_i = 0. \tag{60}$$

Hence, for (58) we have $\frac{k}{\rho_s} = (1+t)\left(\frac{\gamma}{\rho_i} + b_i(\varphi - \alpha_i)\right)$. That means that $\frac{k}{\rho_s(1+t)} = G = \frac{\gamma}{\rho_i} + b_i(\varphi - \alpha_i)$ and hence

$$b_i^* = \frac{\rho_i G - \gamma}{\rho_i\left(\varphi - \alpha_i^*\right)}. \tag{61}$$

Next, for (59) we have $(1+t)q_i\left(\frac{P}{\rho_i} - \alpha_i + \frac{b_i^2}{2}\right) = 0$, and hence

$$\alpha_i^* = \frac{P}{\rho_i} + \frac{b_i^{*2}}{2}. \tag{62}$$

(61) and (62) are exactly equal to (17) and (21). The proof of the latter is easy. Rewriting (61) we have $\rho_i b_i^*\left(\varphi - \alpha_i^*\right) = \rho_i G - \gamma$. Using (62), this becomes $\rho_i G - \gamma = \rho_i b_i^*\left(\varphi - \frac{P}{\rho_i} - \frac{b_i^{*2}}{2}\right)$. Dividing by ρ_i we have

$$G - \frac{\gamma}{\rho_i} - b_i^*\left(\varphi - \frac{P}{\rho_i}\right) = -\frac{b_i^{*3}}{2}.$$

G. Proof of Proposition 5. The complete information solution can be implemented if $\mu_P = \mu_I = 0$ does not yield a contradiction in (50)–(57). Note that if $\mu_P = \mu_I = 0$ it holds that $\lambda_i = tq_i > 0$, and thus $S_i^{*E} = \frac{\gamma b_i^{*E}}{\rho_i} + \frac{\varphi(b_i^{*E})^2}{2} - \frac{P(b_i^{*E})^2}{2\rho_i} - \frac{(b_i^{*E})^4}{8}$ for $i = P, I$ which does not yield a contradiction in (50)–(57). Hence, inserting (22) into (25) and dividing by b_j^{*E}, we have

$$0 \geq \frac{\gamma}{\rho_j} - \frac{Pb_j^{*E}}{2\rho_j} - \frac{\gamma}{\rho_i} + \frac{Pb_j^{*E}}{2\rho_i} \tag{63}$$

Rearranging terms yields

$$\frac{\gamma}{\rho_i} - \frac{\gamma}{\rho_j} \geq \frac{b_j^{*E}}{2}(\frac{P}{\rho_i} - \frac{P}{\rho_j}) \tag{64}$$

Substituting in $i, j = \{I, P\}$ and $j \neq i$, we have

$$b_I^{*E} \leq \frac{2\gamma}{P} \leq b_P^{*E}. \tag{65}$$

H. Incentive compatibility of the complete information solution when there are more than two farmer types and when land quality is malleable at the time of the policy launch. Since land quality is endogenous it holds that $\alpha_i = \alpha_i^E = P(1 - b_i)/\rho_i + b_i^2/2$. Similar to the analysis in Appendix C, assume that farmers of type $i = 1, 2, \ldots, n$ should participate, but now $\bar{\rho}$ is defined by

$$\rho_i > \frac{\gamma + 0.5P\left(b_i^{*N}\right)^2 + \sqrt{\left(\gamma + 0.5P\left(b_i^{*N}\right)^2\right)^2 + 4GP^2(1 - b_i^{*N})}}{2G} = \bar{\rho}. \tag{66}$$

In this case, the Lagrangian of the government's optimization problem (4) is the following:

$$\begin{aligned} L &= \sum\nolimits_{i\in\{1,2,\ldots,n\}} \frac{q_i b_i k}{\rho_S} + \sum\nolimits_{i\in\{1,2,\ldots,n\}} q_i \left[\frac{P^2(1-b_i)^2}{2\rho_i^2} - \frac{b_i^4}{8} - \frac{\gamma b_i}{\rho_i}\right. \\ &\left. -\frac{b_i^2}{2}\left(\varphi - \frac{P(1-b_i)}{\rho_i} - \frac{b_i^2}{2}\right)\right] - t\sum\nolimits_{i\in\{1,2,\ldots,n\}} q_i S_i \\ &+\sum\nolimits_{i\in\{1,2,\ldots,n\}} \lambda_i \left[S_i - \frac{P^2 b_i(2-b_i)}{2\rho_i^2} + \frac{P b_i^2}{2\rho_i} + \frac{b_i^4}{8} - \frac{\gamma b_i}{\rho_i} - \frac{\varphi b_i^2}{2}\right] \\ &+\sum\nolimits_{i\in\{1,2,\ldots,n\}} \sum\nolimits_{j\in\{1,2,\ldots,n\}\setminus\{i\}} \mu_{ij} \left[S_i - \frac{P^2 b_i(2-b_i)}{2\rho_i^2} + \frac{P b_i^2}{2\rho_i} + \frac{b_i^4}{8} - \frac{\gamma b_i}{\rho_i} - \frac{\varphi b_i^2}{2}\right. \\ &\left. -S_j + \frac{P^2 b_j(2-b_j)}{2\rho_i^2} - \frac{P b_j^2}{2\rho_i} - \frac{b_j^4}{8} + \frac{\gamma b_j}{\rho_i} + \frac{\varphi b_j^2}{2}\right], \end{aligned} \tag{67}$$

where $\lambda_i \geq 0$ is the Kuhn–Tucker multiplier associated with type i's participation constraint, and $\mu_{ij} \geq 0$ is the multiplier associated with the incentive compatibility constraint of type $i, j = \{1, 2, \ldots, n\}, j \neq i$. Solving the corresponding Kuhn–Tucker conditions we have the optimal conservation levels implicitly defined by $G - \frac{\gamma}{\rho_i} - \left(\varphi - \frac{P}{\rho_i}\right) b_i^{*N} - \frac{P^2(1-b_i^{*N})}{\rho_i^2} = -\frac{(b_i^{*N})^3}{2}$ and $S_i^{*N} = \frac{P^2 b_i^{*N}(2-b_i^{*N})}{2\rho_i^2} - \frac{P\left(b_i^{*N}\right)^2}{2\rho_i} + \frac{\gamma b_i^{*N}}{\rho_i} + \frac{\varphi\left(b_i^{*N}\right)^2}{2} - \frac{\left(b_i^{*N}\right)^4}{8}$ as the complete information menu of subsidies when land quality is endogenous.

To find when this solution is incentive compatible, we solve $\mu_{ij} = 0$ for all $i, j = \{1, 2, \ldots, n\}, j \neq i$. This yields $\lambda_i = tq_i > 0$, and thus $S_i^{*N} = \frac{P^2 b_i^{*N}(2-b_i^{*N})}{2\rho_i^2} - \frac{P\left(b_i^{*N}\right)^2}{2\rho_i} + \frac{\gamma b_i^{*N}}{\rho_i} + \frac{\varphi\left(b_i^{*N}\right)^2}{2} - \frac{\left(b_i^{*N}\right)^4}{8}$. Substituting S_i^{*N} and π_i^N in (5) and cancelling terms, we find that the complete information solution is incentive compatible if and only if, for all $\{j, i\}$, $j < i$, $P > \gamma$, we have $b_i^{*N} \leq \tilde{b}_{ij}^N(\rho_i, \rho_j) \leq b_j^{*N}$ with $\tilde{b}_{ij}^N(\rho_i, \rho_j) = \left(1 + P\left(\frac{1}{\rho_i} + \frac{1}{\rho_j}\right)\right)^{-1} \left(\frac{2\gamma}{P} + 2P\left(\frac{1}{\rho_i} + \frac{1}{\rho_j}\right)\right)$.

Note that if $j < i$, we have $\rho_j > \rho_i$ due to the ordering of types. Now, let us define $v_{ij} \equiv \rho_j - \rho_i$. In this case, we have $\tilde{b}^N(\rho_i, \rho_j) = \left(1 + P\left(\frac{1}{\rho_i} + \frac{1}{\rho_i + v_{ij}}\right)\right)^{-1} \left(\frac{2\gamma}{P} + 2P\left(\frac{1}{\rho_i} + \frac{1}{\rho_i + v_{ij}}\right)\right)$, and if $P > \gamma$ we have $\partial\tilde{b}^N(\rho_i, \rho_j)/\partial\rho_i = \left(1 + P\left(\frac{1}{\rho_i} + \frac{1}{\rho_i + v_{ij}}\right)\right)^{-2} \left(2\left(\frac{1}{\rho_i^2} + \frac{1}{(\rho_i + v_{ij})^2}\right)(\gamma - P)\right) < 0$. Hence, if $P > \gamma$, the intersection point of the cost functions of farmers i and j is closer to the origin the more impatient the reference farmer type is. Having established the type-specific intersection point, necessary conditions for $b_i^{*N} \leq \tilde{b}^N(\rho_i, \rho_j) \leq b_j^{*N}$ to be non-empty are that $\partial b_i^{*N}/\partial \rho_i < 0$ and $P > \gamma$.

I. Derivation of the second-best solution when land quality is endogenous. We first derive the second-best policy when $b_I^{*E} > \frac{2\gamma}{P}$. The complete information solution with $\mu_P = \mu_I = 0$ cannot be implemented because $\mu_P = 0$ now yields a contradiction in (56). Therefore, we are left with the possibility that $\mu_P > 0$ and $\mu_I = 0$. Now, (53) reads $\lambda_I = \mu_I + tq_I > 0$, so $\lambda_P \geq 0$ and $\lambda_I > 0$. Now, $\lambda_P > 0$ and $\lambda_I > 0$ would imply that $S_i = \frac{\gamma b_i}{\rho_i} + \frac{\varphi b_i^2}{2} - \frac{P {b_i}^2}{2\rho_i} - \frac{{b_i}^4}{8}$ with $i = P, I$; see (54) and (55). However, since $\mu_P > 0$ this implies that $S_P - \frac{\gamma b_P}{\rho_P} - \frac{\varphi {b_P}^2}{2} + \frac{P b_P^2}{2\rho_P} + \frac{{b_P}^4}{8} - S_I + \frac{\gamma b_I}{\rho_P} + \frac{\varphi {b_I}^2}{2} - \frac{P {b_I}^2}{2\rho_P} - \frac{{b_I}^4}{8} = 0$. Substituting $S_i = \frac{\gamma b_i}{\rho_i} + \frac{\varphi b_i^2}{2} - \frac{P {b_i}^2}{2\rho_i} - \frac{{b_i}^4}{8}$ with $i = P, I$ in the latter, and rearranging terms, yields $b_I = \frac{2\gamma}{P}$ which contradicts $b_I^{*E} > \frac{2\gamma}{P}$. Hence, if $\mu_P > 0$ and $\mu_I = 0$ it needs to hold that $\lambda_P = 0$ and $\lambda_I > 0$. In this case the second-best solution reads:

$$\frac{\gamma}{\rho_P} + \left(\varphi - \frac{P}{\rho_P}\right) b_P - \frac{b_P^3}{2} = G, \tag{68}$$

$$\frac{\gamma}{\rho_P} + \left(\varphi - \frac{P}{\rho_P}\right) b_P - \frac{b_P^3}{2} = G - \frac{t}{1+t}\frac{q_P}{q_I}(b_I P - \gamma)(\frac{1}{\rho_P} - \frac{1}{\rho_I}), \tag{69}$$

$$S_P - \frac{\gamma b_P}{\rho_P} - \frac{\varphi {b_P}^2}{2} + \frac{P b_P^2}{2\rho_P} + \frac{{b_P}^4}{8} = S_I + \frac{\gamma b_I}{\rho_P} + \frac{\varphi {b_I}^2}{2} - \frac{P {b_I}^2}{2\rho_P} - \frac{{b_I}^4}{8}, \tag{70}$$

$$S_I - \frac{\gamma b_I}{\rho_I} - \frac{\varphi b_I^2}{2} + \frac{P b_I^2}{2\rho_I} + \frac{b_I^4}{8} = 0. \tag{71}$$

The same analysis for $b_P^{*E} < \frac{2\gamma}{P}$ yields that the only feasible set of Kuhn-Tucker multipliers is $\mu_P = 0$, $\mu_I > 0$, $\lambda_P > 0$, and $\lambda_I = 0$. Hence, in this case the second-best solution also reads (68)–(71) except that all subscripts P should now read I, and vice versa. (68) states that the amount of conservation provided by patient farmers should be such that the marginal costs of conservation equal the social marginal benefits of conservation. Note that since $b_I^{*E} > \frac{2\gamma}{P}$, $b_I P - \gamma > 0$ in (69). Hence, the amount of conservation that is provided by impatient farmers is smaller than the level that would equate marginal conservation cost to the social marginal benefits of conservation. Furthermore, (70) indicates that patient farmers should be indifferent between contracts, while (71) shows that impatient farmers receive compensation that is exactly equal to the conservation costs incurred. Hence, in this case, patient farmers receive informational rents for the conservation they provide, while impatient farmers provide less conservation than is socially desirable.

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