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Bidding for Conservation Contracts

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Summary

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Keywords: Conservation Contracts, Scoring Auctions, Non-enforceable Contract Duration, Real Options

JEL Classification: C61, D44, D86, Q24, Q28

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Bidding for conservation contracts*

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May, 2014

Abstract

Contracts providing payments for not developing natural areas, or for removing cropland from production, generally require long-term commitments. Landowners, however, can decide to prematurely terminate the contract when the opportunity cost of complying with conservation requirements increases. The paper investigates how this can affect bidding behavior in multi-dimensional auctions, where agents bid on both the conservation plan and the required payment, when contracts do not provide for sufficiently strong incentives against early exit. Integrating the literature on scoring auctions with that which views non-enforcement of contract terms as a source of real-options, the paper offers the following contributions. First, it is shown that bidders' expected payoff is higher when facing enforceable project deadlines. Second, that failure to account for the risk of opportunistic behavior could lead to the choice of sellers who will not provide the contracting agency with the highest potential payoff. Finally, we examine the role that eligibility rules and the degree of competition can play in avoiding such potential bias in contract allocation.

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1 Introduction

Recent decades have witnessed an increasing interest by governments in procuring the provision of environmental goods and services, such as biodiversity, carbon sequestration, soil erosion control, flood-water storage, by stipulating contracts which provide payments for not converting natural and semi-natural areas into agriculture or other productive uses, or for setting aside cropland.[1] Landowners generally have also to commit to environmental quality enhancements, such as establishing permanent native grasses on set-aside cropland, or implementing wildlife protection measures on enrolled forestlands and wetlands.

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[1] Similar contracts have also been made for buying back water abstraction licenses from farmers to ensure minimal in-stream flow levels in drought years (Cummings et al., 2003) or for the permanent decommissioning of fishing vessels (Larkin et al., 2004).

Traditionally, governments have offered fixed payments for compliance with a predetermined set of conservation practices. However, along with the expansion of environmental contracting, interest in bidding mechanisms has grown, in order to increase the cost-effectiveness, transparency and political acceptance of public payments (Latacz-Lohmann and Schilizzi, 2005). This has brought a growing literature on conservation auctions, with various papers dealing with multi-dimensional schemes, where agents bid on both conservation plans and the required payment, and offers are evaluated according to predefined scoring rules (see Kirwan et al., 2005; Claassen et al. 2008; Espinosa-Arredondo, 2008; Vukina et al., 2008; Wu and Lin, 2010). Examples of such bidding schemes include the Conservation Reserve Program (CRP) auctions employed in the USA after 1990, the BushTender Trial in Australia and the Challenge Fund Scheme in UK.[2]

Models of conservation auctions, however, are usually set up by assuming contract enforcement. Yet, like other economic transactions, conservation contracts are prone to the risk of breach which may arise when the opportunity cost of compliance with environmental requirements increases. For instance, compliance costs can be boosted by sharp rises of crop prices, increasing returns in timber harvesting, rising residential land prices or the discovery of mineral resources in commercial quantities on enrolled lands. In that case, if landowners do not face adequate disincentives for infringement, they can decide to prematurely terminate the program and, by so doing, prevent the achievement of environmental goals which typically require long-term commitment.

Infringement of contracts may be deterred by informal sanctions, such as the threat of losing reputation and future business. Reputational incentives, however, tend to play a relatively limited role in exchanges between the government and the private sector (Kelman, 1990), where open competition is seen as an instrument to limit civil servants' discretion in the allocation of public funds (Spagnolo, 2012). This makes more compelling the need for legal remedies for breach of contracts, typically taking on the form of financial penalties[3], which, however, may prove to be insufficient to prevent early exit. This can be due to several circumstances.

First, buyers can find it difficult to tailor contractual penalties, owing to the lack of precise information on the bidders' outside option values. Second, public procurement regulations or general legal principles may limit the freedom to stipulate penalties for contract breach (Dosi and Moretto, 2013). For example, under the Common Law of Liquidated Damages, payments for breach, even though mutually agreed, can be subsequently voided (in part or in their entirety) by courts if it appears that they were designed to be a deterrent rather a reasonable pre-assessment of damages that could be suffered in the event of breach (DiMatteo, 2001).[4] [5] Third, governments can face political pressure to soft penalties for the termination of conservation agreements. In the USA, for example, agricultural associations have frequently lobbied for reducing payments for early release of CRP contracts, and in 2011 some Members of the Congress asked President Obama to release CRP land without penalty for the purpose of grain production (Stubbs, 2013). Finally, the effec-

[2]For a review of conservation auctions employed in the USA, Europe and Australia, see Latacz-Lohmann and Schilizzi (2005).

[3]For example, in the EU, the voluntary cropland set-aside program introduced in 1988 provided that Member States "shall apply financial penalties [...] in the case of failure to comply with undertakings made" (EEC, 1988, Art.15). In the USA, besides returning all the cost-share funds already paid, with interest, owners willing to take their land out of the CRP program face a penalty of 25 per cent of rental payments received. The Secretary of Agriculture, however, is allowed to release land from CRP without penalty, an option which has been exercised twice, in 1995 and 1996 (Stubbs, 2013).

[4]This explains why, for example, the CRP contract specifies that the fee due in the event of early release "shall be due as liquidated damages [...] and not as a penalty" (USDA, 2013, § 10).

[5]Though being traditionally justified on fairness grounds, various authors have argued that the Common Law of Liquidated Damages can also be justified on efficiency grounds (see, for example, Goetz and Scott, 1977; Shavell, 1980). For a different approach, see Dosi and Moretto (2013).

tiveness of contractual claims can be threatened by institutional failures involving costly litigation and inefficient dispute settlement processes. Institutional failures, leading to incomplete contract enforcement, have been emphasized in recent works on programs aimed at reducing deforestation and degradation of tropical forests in developing countries (Palmer, 2011; Cordero-Salas and Roe, 2012; Cordero, 2013).

When the enforcement of contractual obligations is lessened or threatened by the lack of reputational incentives, the inherent weakness of penalties or the weak enforcement of contractual claims, buyers will find themselves deprived of (adequate) protection against the risk of non-compliance by the seller. The question addressed here is how this can affect bidding behavior in conservation auctions and the parties' individual payoffs.

The paper builds on two strands of literature that have largely been evolving separately. The first is that on scoring auctions, starting with Che (1993), whereby the buyer, caring about attributes other than price, asks agents to bid on both the quality of the procured item and the required payment, and the contract is awarded to the bidder who got the highest score. Asker and Cantillon (2010) provides a review of recent developments in the theory of multi-dimensional auctions.

The second strand is that which views imperfect enforcement of procurement contract terms as a source of real-options. Within this literature, most papers have focussed on the effects of managerial flexibility upon the *ex-post* value of the project to the seller, by overlooking the feedback effects of flexibility on bidding behavior (see, for example, Ford et al., 2002; Ho and Liu, 2002; Garvin and Cheah, 2004; You and Tam, 2006; Lo et al., 2007). One of the few exceptions is the paper by Dosi and Moretto (2013) that studies the effects of the buyer's inability to enforce compliance with delivery schedules on competitive bids for public works. The authors, however, limit their analysis to homogeneous projects, where bidding is restricted to the price dimension.

Integrating these two strands of literature, we build a model aimed at examining how bidding behavior, in multi-dimensional auctions, can be affected by the managerial flexibility spurred by the lack of incentives against early release of conservation agreements. While the paper is written in the context of environmental contracting, the contents may be applicable to other procurement situations where buyers face the risk of interruption of supply, due to outside opportunities that are valuable for the sellers.

The paper offers the following contributions. First, it is shown that bidders' expected payoff is higher when facing enforceable project deadlines. Second, that failure to account for the risk of opportunistic behavior could lead to the choice of sellers who will not provide the buyer with the highest potential payoff. Finally, we examine the role that eligibility rules and the degree of competition may play in avoiding such potential "bias" in contract allocation.

Section 2 describes the model and the main assumptions. Section 3 examines the case where the contract duration, set at the time of award, is enforceable, while Section 4 and 5 analyze the outcome of the bidding process when sellers do not face incentives against early exit. We conclude in Section 6. The Appendix contains the proofs omitted from the text.

2 Model set up and assumptions

Consider $n \geq 2$ risk-neutral agents, each one holding one unit of the asset L that is currently kept "idle", meaning that it does not provide the owners with any (relevant) private benefit. All parcels are suitable for producing one unit of a marketable good (*good 1*).[6] This, however, requires developing the asset, by affording a sunk investment cost, $K(\theta_i)$, where $\theta_i \in [\theta^l, \theta^u]$ denotes the

[6] We normalize the quantity of *good 1* at no cost in terms of robustness of our results.

agent's innate managerial skills. $K(\theta_i)$ is continuous, differentiable and decreasing in θ_i ($K_\theta < 0$).[7] Without any loss of generality, operational costs are normalized at zero. Profits resulting from developing L will depend on the output price, $p(t)$, which is assumed to be totally exogenous and following the dynamics:[8]

$$dp(t) = \sigma p(t) d\chi(t), \text{ with } p(0) = p_0 \tag{1}$$

where σ is the instantaneous volatility and $d\chi(t)$ is the increment of the standard Wiener process satisfying $E_0\left[d\chi(t)\right] = 0$ and $E_0\left[d\chi(t)^2\right] = dt$.

Now consider a public agency (henceforth, "the buyer") willing to procure the provision of an environmental service (*good 2*) over a period of time. Provision of *good 2* requires the seller to keep L in its current pristine state, as well as to undertake on-site activities affecting the service (quality or quantity) level.[9] Letting g denote the service level, the per-unit-of-time direct cost of conservation practices is given by $c(g, \theta_i)$, which is strictly increasing and convex in g, and decreasing in θ_i ($c_g > 0$, $c_{gg} > 0$, $c_\theta \leq 0$). We also assume that $c_{g\theta} < 0$ and we exclude the presence of fixed costs, $c(0, \theta_i) = 0$.

The contract is awarded through competitive tendering. Specifically, agents are solicited at time $t = 0$ to bid on the service level ($g > 0$) and on the payment ($b \geq 0$) required for supplying g at each time period $t \in (0, \overline{T}]$. Bids are then evaluated according to a scoring rule, $\overline{S}(b, g)$, announced prior to start the bidding process, and the winner is the agent with the highest score.

■ **Additionality.** Consistently with most current conservation programs we shall assume that public funding is allowed only for sustaining private decisions that would have not been made anyway.[10]

■ **Scoring rule.** Bids are evaluated on the basis of the present value of the public benefits attributed to conservation practices, net of the discounted flow of rental payments:

$$\overline{S}(b, g) = \int_0^{\overline{T}} s(b, g) e^{-rz} dz = (v(g) - b) \frac{1 - e^{-r\overline{T}}}{r}, \tag{2}$$

where $\overline{T}$ is the project deadline established by the buyer prior to start the bidding process, r is the discount rate, and $v(g)$ is a function mapping the social utility attached to conservation, with $v(0) = 0$, $v_g(g) > 0$ and $v_{gg}(g) \leq 0$.[11] In what follows, $s(b, g)$ will be referred to as the instantaneous score, while $\overline{S}(b, g)$ as the total score or the buyer's total payoff.

[7] $K(\theta_i)$ can also be thought as the present value of a flow of periodic fixed costs $k(\theta_i) = rK(\theta_i)$ to which the agent commits once investment is undertaken.

[8] In Eq. (1) we abstract from the drift in order to focus on the impact that uncertainty has on outcome of the bidding process. Note, however, that by the Markov property of Eq. (1), our results would not be qualitatively altered by using a non-zero trend for p_t. It can be also easily shown that Eq. (1) is consistent with the case of a firm maximizing instantaneous operating profits under a Cobb-Douglas production technology (see Dixit and Pindyck, 1994, pp. 195-199).

[9] We are setting our focus on contracts proposed to agents holding land which is still in its pristine state. Conservation programs usually labelled as Payment for Ecosystem Services (PES) fit within this category. Our approach, however, can be easily extended to deal with situations, as the one addressed by Gulati and Vercammen (2006), where agents can choose between a resource conserving technology (A) and a resource depleting one (B). Basically, in that case, the seller accepts to use technology A until date $\bar{T}$, and then may switch back to technology B once the contract expires. Comparing this case with ours, the main difference is given by the initial state of the input asset used to provide the environmental service. In the first case, the seller is required to suspend operations under technology B and switch to A for a certain time period. In contrast, in our case, the seller is asked to postpone the exercise of the option to switch to B.

[10] On the additionality principle, see, for example, Ferraro (2008).

[11] This functional form is consistent with the scoring rules used by Kirwan et al. (2005), Vukina et al. (2008) and Wu and Lin (2010) to analyze the effects of the Conservation Reserve Program. Notice that our framework can be easily extended to the case where the service level $g(t)$ evolves deterministically at a given exogenous rate.

■ **Information.** Prior to bidding agents have private information about their own type θ_i. Bidder i only knows that θ_j, $j \neq i$ is drawn from a common prior cumulative distribution $F(\theta_i)$, with continuously differentiable density $f(\theta_i)$ defined on a positive support $[\theta^l, \theta^u] \subseteq R_+$. The process (1), which is independent of θ_i, is common knowledge, and its realizations $\{p(t), t > 0\}$ are publicly observed information.

■ **Other assumptions:**

■ **Assumption 1:** The inverse hazard rate $F(\theta_i)/f(\theta_i)$ is increasing in θ.

■ **Assumption 2:** $\Delta(g, \theta_i) = c(g, \theta_i) - rK(\theta_i)$ is positive and non-increasing in θ_i for every $\theta_i \in [\theta^l, \theta^u]$ and its derivative is bounded above.

■ **Assumption 3:** At each time period, g is verifiable by all parties.

■ **Assumption 4:** The buyer is able to commit to carry out the terms of the contract for its entire duration.

Assumption 1 is standard in the auction literature (see, for example, Krishna, 2009). Assumption 2 is made in order to guarantee strict monotonicity of the scoring rule (Che, 1993). It implies that, as θ increases, the cost-efficiency in the provision of *good 2* dominates the cost-efficiency in the production of *good 1*.[12] Assumption 3, which is made to focus purely on the effects of opportunistic behavior leading to early exit, indicates that the buyer is able to monitor compliance with the promised environmental service and to stop rental payments should g fall below the contractual specifications.[13] By Assumption 4 we suppose that the buyer can credibly commit not to use right after the auction ($t > 0$) the information extracted through the bidding process to lower the rental rate or to ask the seller to increase efforts in service provision.

3 Perfect enforcement

We first analyze the outcome of the bidding process when the expiry date of the contract is enforceable. Implicitly, we assume that the buyer does not face any constraints to stipulate and to costlessly enforce arbitrarily large penalties against early exit or, equivalently, that the level of liquidated damages is such that agents bid knowing that they will never find it convenient to exercise the option to prematurely terminate the contract.[14]

3.1 Preferences

Prior to bidding each agent contemplates the opportunity of developing L for producing *good 1*. Denoting by $\widehat{p}_i$ the output price triggering investment in such venture for the ith agent, the private value of the development project is given by:

$$\widehat{\Pi}(\theta_i) = E_0[e^{-r\widehat{T}_i}[\int_{\widehat{T}_i}^{\infty} p(z)e^{-r(z-\widehat{T}_i)}dz - K(\theta_i)]] = E_0[e^{-r\widehat{T}_i}](\frac{\widehat{p}_i}{r} - K(\theta_i)), \tag{3}$$

[12] The underlying assumption is that, being *good 1* a rather conventional product, individual managerial skills play a relatively less important role in explaining cost differences across agents.

[13] Problems related to imperfect monitoring of conservation activities, or actual environmental outcomes, have been discussed in a series of papers dealing with agri-environmental contracts. See, among others, Giannakas and Kaplan (2005) and Hart and Latacz-Lohmann (2005). On outcome vs. action-based conservation contracts see also Whitten et al. (2007), Gibbons et al. (2011) and White and Sadler (2011).

[14] As shown later (see footnote 19), this for example might be the case when sellers, willing to terminate the contract, would be required to refund the buyer for the whole payments already received, with interest, plus a fee. This approach, adopted in USA for the CRP contracts, could explain the relatively low number of CRP acres withdrawn early.

where the optimal time of investment, $\widehat{T_i} = \inf\{t \geq 0 \mid p(t) = \widehat{p_i}\}$, is a random variable, and E_0 is the expectation taken at the starting period $t = 0$ over the process $\{p(t), t \geq 0\}$. Eq. (3) represents the seller's opportunity cost of keeping L in its pristine state as well as the value of the asset for the bidders who will not be awarded the conservation contract.

The optimal trigger, $\widehat{p_i}$, is the solution of the following problem:

$$\hat{V}(\theta_i) = \max_{\widehat{T_i}} E_0[e^{-r\widehat{T_i}}](\frac{\widehat{p_i}}{r} - K(\theta_i)) = \max_{\widehat{p_i}}(\frac{p_0}{\widehat{p_i}})^{\beta}(\frac{\widehat{p_i}}{r} - K(\theta_i)), \tag{4}$$

where $E_0[e^{-r\widehat{T_i}}] = (p_0/\widehat{p_i})^{\beta}$ is the expected discount factor, and $\beta > 1$ is the positive root of the characteristic equation $\phi(\beta) = (\sigma^2/2)\beta(\beta - 1) - r = 0$.[15]

Solving problem (4), we get:

$$\widehat{p_i} \equiv \widehat{p}(\theta_i) = [\beta/(\beta - 1)]rK(\theta_i), \tag{4.1}$$

$$\hat{V}(\theta_i) = [\Gamma(p_0)/(\beta - 1)]K(\theta_i)^{1-\beta}, \tag{4.2}$$

where $\Gamma(p_0) = [\frac{p_0/r}{\beta/(\beta-1)}]^{\beta}$. As standard in the real-option literature, the optimal trigger is then given by the user cost of capital, $rK(\theta_i)$, corrected by the option multiple, $\beta/(\beta - 1)$, in order to account for the irreversibility and the uncertainty characterizing the decision to develop L for production use.

Notice that $d\hat{V}(\theta_i)/d\theta_i > 0$ and $d\widehat{p}(\theta_i)/d\theta_i < 0$. That is, the more efficient is the agent, the higher are the value of the asset and the opportunity cost of keeping L idle, and the lower is the market price making profitable to put it into commercial production.

According to the additionality principle, public payments are allowed only for supporting decisions that would have not been made anyway. Since, in our frame, additionality passes through the actual threat of having L developed for commercial use, to ensure that all n bidders are eligible for conservation funding we add the following assumption, which says that the current level of market revenues is such that, without public support, none of the bidders would continue to keep L idle.

■ **Assumption 5:** $p_0 = \widehat{p}(\theta^l)$.

Given the properties of $\widehat{p}(\theta_i)$, Assumption 5 allows to normalize our frame by setting $\widehat{\Pi}(\theta^l) = 0$. This operation, which does not affect the underlying ranking of agents with respect to the profitability of developing L, implies that bidders can be ranked according to the following reservation value:

$$\widehat{\Pi}(\theta_i) = \frac{p_0}{r} - K(\theta_i), \text{ for } \theta_i \in [\theta^l, \theta^u], \tag{3.1}$$

which is increasing in the cost parameter θ.

Now consider the winning bidder. By Assumption 5, the *ex-post* value of the contract is given

[15] The expected present value, $E_0[e^{-r\widehat{T_i}}]$, can be determined by using dynamic programming (see e.g. Dixit and Pindyck, 1994, pp. 315-316).

by:[16]

$$\begin{aligned}\Pi(b_i, g_i; \theta_i) &= (b_i - c(g_i, \theta_i))\frac{1-e^{-r\overline{T}}}{r} + (E_0[p_{\overline{T}}] - rK(\theta_i))\frac{e^{-r\overline{T}}}{r} \\ &= (b_i - c(g_i, \theta_i))\frac{1-e^{-r\overline{T}}}{r} + (p_0 - rK(\theta_i))\frac{e^{-r\overline{T}}}{r}, \end{aligned} \tag{5}$$

where $E_0[p_{\overline{T}}] = p_0$ is a straightforward implication of the Markov property of the diffusion process (1).[17] By subtracting Eq. (3.1) from Eq. (5), we get:

$$\Pi(b_i, g_i; \theta_i) - \widehat{\Pi}(\theta_i) = \begin{cases} [(b_i - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))]\frac{1-e^{-r\overline{T}}}{r}, & \text{for } \theta_i \in (\theta^l, \theta^u], \\ (b_i - c(g_i, \theta_i))\frac{1-e^{-r\overline{T}}}{r}, & \text{for } \theta_i = \theta^l. \end{cases} \tag{6}$$

The seller's pay-off (accounting for its reservation value) is then given by the difference between the present value of the stream of rental payments (net of the cost of performing g_i) and the opportunity cost of not developing L until the expiration of the contract. Notice that, by Assumption 5, the latter is null for the agent having the highest development cost (θ^l).

3.2 Equilibrium strategy

Given the information set at time $t = 0$, each agent will choose the optimal bidding strategy by maximizing the following functional:

$$\Pi(\overline{S}_i) = \Pi(b_i, g_i; \theta_i) \cdot \Pr(\text{of win}/\overline{S}_i) + \Pi(0, 0; \theta_i) \cdot (1 - \Pr(\text{of win}/\overline{S}_i)), \tag{7}$$

where $\Pr(\text{of win}/\overline{S}_i)$ is the probability of winning the auction, conditional on the reported score $\overline{S}_i(b_i, g_i)$, and $\Pi(0, 0; \theta_i) = \widehat{\Pi}(\theta_i)$ is the reservation value.

Hence, at $t = 0$, with probability $\Pr(\text{of win}/\overline{S}_i)$, agent i will be entitled to receive a flow of net payments worth $(b_i - c(g_i, \theta_i))(1 - e^{-r\overline{T}})/r$, plus the value of developing the asset at the expiration of the contract, $e^{-r\overline{T}}[(p_0/r) - K(\theta_i)]$. Instead, with probability $(1 - \Pr(\text{of win}/\overline{S}_i))$, the agent will simply get the reservation value: $\Pi(0, 0; \theta_i) = \widehat{\Pi}(\theta_i) \geq 0$.

Agents participate in the auction only if the following individual rationality constraint holds:

$$\Pi(\overline{S}_i) \geq \widehat{\Pi}(\theta_i) \geq 0. \tag{8}$$

Notice that, since agents bid knowing that $\overline{T}$ is enforceable, the probability of winning, $\Pr(\text{of win}/\overline{S}_i)$, is equivalent to $\Pr(\text{of win}/s_i)$, where s_i is the instantaneous score. Hence, by using (6),

[16] More generally, the contract value is given by:

$$\begin{aligned}\Pi(b_i, g_i; \theta_i) &= \int_0^{\overline{T}} (b_i - c(g_i, \theta_i))e^{-rz}dz + e^{-r\overline{T}}\Big\{\Pr(\overline{T} \geq \widehat{T}_i; t=0) \cdot E_0\left[(p_{\overline{T}}/r) - K(\theta_i)\right] + \\ &+ \Pr(\overline{T} < \widehat{T}_i; t=0) \cdot E_0[e^{-r(\widehat{T}_i - \overline{T})}(\int_{\widehat{T}_i}^{\infty} p(z)e^{-rz}dz - K(\theta_i))]\Big\}.\end{aligned}$$

that is, the present value of the flow of rental payments minus directs costs, accruing up to $\overline{T}$ (first term), plus the value of the option to invest in the production of *good 1* (second and third term), where $\Pr(\overline{T} \geq \widehat{T}_i; t=0)$ indicates the probability that, with the information available at time zero, $\widehat{p}_i$ is hit before $\overline{T}$. Note that, consistently, we weight by their respective probability two possible situations: i) with $\Pr(\overline{T} \geq \widehat{T}_i)$ investment occurs at $\overline{T}$ as soon as the contract expires, and ii) with $\Pr(\overline{T} < \widehat{T}_i)$ the agent keeps open the option to invest which, as shown above, it should be exercised at the optimal (random) stopping time $\widehat{T}_i$. Finally, note that, by Assumption 5, $\Pr(\overline{T} \geq \widehat{T}_i; t=0) = 1$.

[17] See, for example, Dixit and Pindyck (1994, pp. 71-74).

we can rearrange (8) and define agent i's objective function as follows:

$$\bar{W}(b_i, g_i; \theta_i) = \{[(b_i - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - e^{-r\overline{T}}}{r})\} \Pr(\text{of win}/s_i). \tag{9}$$

Following Che (1993, Lemma 1, p. 672), each agent's bidding strategy can be equivalently illustrated by selecting a score and the service level. This allows to determine s_i and g_i separately, with the latter being equal to:

$$g(\theta_i) = \arg\max\left[v(g_i) - c(g_i, \theta_i)\right], \text{ for all } \theta_i \in [\theta^l, \theta^u], \tag{10}$$

where, by the Envelope Theorem:

$$dg(\theta_i)/d\theta_i = c_{g\theta}(g(\theta_i), \theta_i)/(v_{gg}(g(\theta_i)) - c_{gg}(g(\theta_i), \theta_i)) > 0. \tag{10.1}$$

The solution of the bidding game is presented in Proposition 1.

Proposition 1 *When the contract duration is enforceable, for any finite number of bidders n it will always exist an equilibrium in symmetric and strictly increasing strategies $\bar{s}(\theta_i)$ characterized by:*

i) the service level $g(\theta_i)$ (defined by Eq. (10)),

ii) the bidding function:

$$\bar{b}(\theta_i) = c(g(\theta_i), \theta_i) + (p_0 - rK(\theta_i)) - \int_{\theta^l}^{\theta_i} \Delta_\theta(x)\frac{F^{(n)}(x)}{F^{(n)}(\theta_i)}dx, \tag{11}$$

iii) the expected profits:

$$\bar{W}(\theta_i) = -\int_{\theta^l}^{\theta_i} \Delta_\theta(x)\frac{1 - e^{-r\overline{T}}}{r}F^{(n)}(x)dx, \tag{12}$$

where $\Delta_\theta(x) \equiv c_\theta(g(x), x) - rK_\theta(x) < 0$.

Proof. See Appendix A.1 ■

Since $\overline{T}$ is established prior to start the bidding process, the buyer's total payoff simply comes from the instantaneous score, $\bar{s}(\theta_i) = v(g(\theta_i)) - \bar{b}(\theta_i)$. Therefore, the auction efficiency is ensured by showing that $d\bar{s}(\theta_i)/d\theta_i > 0$ (see Appendix A.1).

By Eq. (11) we note first that the bid price, besides covering the cost of performing the promised conservation practices, $c(g(\theta_i), \theta_i)$, also covers the indirect cost of renouncing to develop L, $(p_0 - rK(\theta_i))$. Second, agents must be compensated by information rents, $-\int_{\theta^l}^{\theta_i} \Delta_\theta(x)\frac{F^{(n)}(x)}{F^{(n)}(\theta_i)}dx$. As standard in the auction literature, no rents will be paid to the least cost-efficient agent: $\bar{b}(\theta^l) = c(g(\theta^l), \theta^l) + (p_0 - rK(\theta^l))$.

4 Non-enforceable contract duration

Suppose now the buyer is unable to ensure compliance with the stipulated project deadline. For the sake of simplicity, we shall assume that the seller does not face any (credibly-enforceable) penalty for early exit.[18] Thus, agents bid knowing that, should an attractive outside option arise, they can terminate the contract at the only cost of losing from that time onward conservation payments. As shown henceforth, this implies that unlike the previous case, agents' bidding strategies will be affected by endogenous timing considerations.

4.1 Preferences

As above, prior to bidding, each agent contemplates the opportunity of developing L, which is worth $\widehat{\Pi}(\theta_i)$ as defined by Eq. (3.1). Now consider the winner. Denoting by p_i^* the optimal threshold for developing L, the *ex-post* value of the project is given by:

$$\begin{aligned}\Pi(b_i, g_i; \theta_i) &= E_0[\int_0^{T_i} (b_i - c(g_i, \theta_i))e^{-rz}dz + e^{-rT_i}(\int_{T_i}^{\infty} p(z)e^{-r(z-T_i)}dz - K(\theta_i))] \\ &= (b_i - c(g_i, \theta_i))\frac{1 - E_0[e^{-rT_i}]}{r} + (p_i^* - rK(\theta_i))\frac{E_0[e^{-rT_i}]}{r}, \qquad (14)\end{aligned}$$

where $T_i = \inf\{t \geq 0 \mid p(t) = p_i^*\}$ is the optimal time for breaching the contract. The first term in Eq. (14) is the expected net present value of conservation payments, while the second term is the expected net present value of switching to the production of *good 1*.[19]

By rearranging Eq. (14), the seller's optimal trigger is given by the solution of the following problem:

$$\begin{aligned}V(b_i, g_i, \theta_i) &= \max_{T_i} E_0[e^{-rT_i}]\frac{p_i^* - [(b_i - c(g_i, \theta_i)) + rK(\theta_i)]}{r} \\ &= \max_{p_i^*}(\frac{p_0}{p_i^*})^{\beta}\frac{p_i^* - [(b_i - c(g_i, \theta_i)) + rK(\theta_i)]}{r}. \qquad (15)\end{aligned}$$

where $E_0[e^{-rT_i}] = (p_0/p_i^*)^{\beta} < 1$. In Eq. (15), the term in squared brackets represents the cost of switching to the production of *good 1*, which, besides the direct cost, $rK(\theta_i)$, must also account for the forgone net rental payments, $b_i - c(g_i, \theta_i)$.

Solving problem (15), we get:

$$p_i^* \equiv p^*(b_i, g_i, \theta_i) = \frac{\beta}{\beta - 1}[(b_i - c(g_i, \theta_i)) + rK(\theta_i)], \qquad (15.1)$$

$$V(b_i, g_i, \theta_i) = [\Gamma(p_0)/(\beta - 1)](\frac{b_i - c(g_i, \theta_i)}{r} + K(\theta_i))^{1-\beta}. \qquad (15.2)$$

Subtracting $\widehat{\Pi}(\theta_i)$ from Eq. (14) yields the value attached to having the contract awarded:

$$\Pi(b_i, g_i; \theta_i) - \widehat{\Pi}(\theta_i) = \begin{cases} [(b_i - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))]\frac{1-E_0[e^{-rT_i}]}{r} + \\ +(p_i^* - p_0)\frac{E_0[e^{-rT_i}]}{r} & \text{for } \theta_i \in (\theta^l, \theta^u] \\ (b_i - c(g_i, \theta_i))\frac{1-E_0[e^{-rT_i}]}{r} + (p_i^* - p_0)\frac{E_0[e^{-rT_i}]}{r}, & \text{for } \theta_i = \theta^l. \end{cases} \qquad (16)$$

[18] Note, however, that the model can be easily extended, to include a probability-based penalty for early exit, provided the expected penalty for breach does not exceed the seller's outside option value (see Dosi and Moretto, 2013).

[19] Notice that if, in the event of early exit ($T_i < \bar{T}$), the buyer imposed the repayment of the whole funds already paid:

$$\Pi(b_i, g_i; \theta_i) = E_0[\int_0^{T_i} -c(g_i, \theta_i)e^{-rz}dz + e^{-rT_i}(\int_{T_i}^{\infty} p(z)e^{-r(z-T_i)}dz - K(\theta_i))] < \widehat{\Pi}(\theta_i)$$

In this case, none of the bidders would find it profitable to prematurely terminate the contract.

Comparison between Eq. (6) and Eq. (16) points out the value of the managerial flexibility embedded in the opportunity of early exit. It shows that the lack of incentives against breach alters the seller's expected payoff, namely, by lowering the opportunity cost of engaging into the conservation program.

4.2 Equilibrium strategy

Suppose the buyer ignored the risk of opportunistic behavior by the seller and, as above, ranked bids on the basis of the instantaneous score, $s(b_i, g_i)$, by (implicitly) assuming that $\overline{T}$ will be obeyed.

Agents will set their bids by maximizing the following functional

$$\Pi(s_i) = \Pi(b_i, g_i; \theta_i) \cdot \Pr(\text{of win}/s_i) + \Pi(0, 0; \theta_i) \cdot (1 - \Pr(\text{of win}/s_i)), \tag{17}$$

where $\Pi(0, 0; \theta_i) = \widehat{\Pi}(\theta_i)$ is the reservation value, and they will participate in the auction only if the individual rationality constraint holds: $\Pi(s_i) \geq \widehat{\Pi}(\theta_i)$.

Using Eq. (16) and Eq. (17), we can define bidder i's objective as follows:

$$\begin{aligned} W(b_i, g_i; \theta_i) &= \{[(b_i - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - E_0[e^{-rT_i}]}{r} + \\ &\quad +(p_i^* - p_0)\frac{E_0[e^{-rT_i}]}{r}\} \Pr(\text{of win}/s_i). \end{aligned} \tag{18}$$

In Appendix A.2 we prove that Che's Lemma 1 still holds. Hence, we can separately determine g_i and s_i, and proceed to the solution of the bidding game.

Proposition 2 *When the contract duration is not enforceable, for any finite n it will always exist an equilibrium in symmetric, strictly increasing strategies $s(\theta_i)$, characterized by:*

i) the service level $g(\theta_i)$ (defined by Eq. (10)),

ii) the bidding function:

$$\begin{aligned} b(\theta_i) &= c(g(\theta_i), \theta_i) + (p_0 - rK(\theta_i)) + \\ &\quad - \frac{\int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{1-E_0[e^{-rT_i(x)}]}{r} \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx + (p^*(\theta_i) - p_0)\frac{E_0[e^{-rT_i(\theta_i)}]}{r}}{\frac{1-E_0[e^{-rT_i(\theta_i)}]}{r}}, \end{aligned} \tag{19}$$

iii) the expected profits:

$$W(\theta_i) = -\int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{1 - E_0[e^{-rT_i(x)}]}{r} F^{(n)}(x) dx, \tag{20}$$

where, by (8), $W(\theta^l) = 0$.

Proof. See Appendix A.2. ∎

As shown in Appendix A.2, even when the project deadline is not enforceable, using the instantaneous score allows to select the least-cost agent, that is, $ds(\theta_i)/d\theta_i > 0$ (see Appendix A.2). Further, as above, the bid price $b(\theta_i)$ will cover the direct cost of providing the *good 2* as well as the opportunity cost of postponing the production of *good 1*.

Comparison between Eq. (11) and Eq. (19) however shows that, when the contract duration is not enforceable, the bid price is lowered by the term $(p^*(\theta_i) - p_0)\frac{E_0[e^{-rT_i(\theta_i)}]}{r}$.[20] The magnitude

[20] Notice that both the information rents and the gains associated with anticipating the development of L for commercial purposes are annualized by the term $(1 - E_0[e^{-rT_i(\theta_i)}])/r$.

of such reduction, which accounts for the potential gains associated with early exit, depends on the uncertainty about the profits resulting from contract breach. It is easy to show that: $\sigma \to \infty$, $E_0[e^{-rT_i(\theta_i)}] \to 0$ for all θ_i. That is, the higher is the uncertainty about market profits, the lower is the difference between the bid price with and without contract enforcement, since the today's value to invest in developing L tends to vanish as uncertainty increases.

Since information rents are null for agent θ^l, we get:

$$b(\theta^l) = c(g(\theta^l), \theta^l) + (p_0 - rK(\theta^l)) - p_0 \frac{E_0[e^{-rT_i(\theta^l)}]}{\beta - (1 - E_0[e^{-rT_i(\theta^l)}])} < \bar{b}(\theta^l), \tag{19.1}$$

from which it is easy to show that $[\beta/(\beta-1)](b(\theta^l) - c(g(\theta^l), \theta^l) + rK(\theta^l)) = p^*(\theta^l) > p_0$. In other words, the managerial flexibility, spurred by the non-enforcement of contract terms, tends to intensify the competition among the bidders.

In light of these results, let us analyze the effect of managerial flexibility upon the parties' individual payoffs. We first consider the seller. The following proposition compares the outcome of the bidding process when the project deadline is enforceable with that when the contract does not provide for sufficiently strong incentives against early exit.

Proposition 3 *Whatever is $\overline{T}$: (i) the rental payment is lower when the contract duration is not enforceable, $b(\theta_i) < \bar{b}(\theta_i)$; (ii) the seller's expected payoff is lower when the contract duration is not enforceable, $W(\theta_i) < \bar{W}(\theta_i)$, unless $T_i > \overline{T}$, in which case $W(\theta_i) = \bar{W}(\theta_i)$.*

Proof. See Appendix A.3. ■

The first result is consistent with other findings, such as those of Spulber (1990), who pointed out that, in the absence of enforcement, the most efficient (low cost) bidders will be forced to bid low in order to preserve their chances of winning. This, in turn, rises the probability of breach of contracts. Unlike Spulber, however, we find that the possibility of adjusting the service period allows preserving the efficiency of the bidding process, that is, the auction does not fail to allocate the contract to the bidder having the lowest cost of undertaking conservation activities.

The second result states that bidders' expected payoff is higher when facing an enforceable project deadline, since the potential benefits, stemming from the exit option, are outweighed by the stronger bid competition spurred by the non-enforceability of contract terms. This result is similar to that obtained by Dosi and Moretto (2013) in a paper dealing with the effects of the managerial flexibility related to the time to completion of public works procured through price-only auctions.

The literature on security-bid auctions provides an interpretation for the finding that bidders' payoff is lower when competing for a conservation contract with a nested early-exit option. Notice, in fact, that when the contract duration is enforceable, bidders bid knowing that, upon winning, they will give up their opportunity to develop L until $\overline{T}$. Since $\overline{T}$ is exogenously established by the buyer, this is equivalent to selling an option by a cash auction. On the other hand, when $\overline{T}$ is not enforceable, agents bid knowing that they can prematurely terminate the contract at the price of only losing rental payments. This, in essence, is equivalent to bidding for a state-contingent contract, which, as shown by the literature on security-bid auctions, will deliver an outcome for the seller that is lower than that achievable by a cash auction.[21]

[21] For an overview of auctions with contingent payments, see Skrzypacz (2013).

5 The buyer's payoff

When the project deadline is not enforceable, the buyer's total expected payoff is given by:

$$S(\theta_i) = s(\theta_i)\frac{1 - E_0[e^{-rT_i(\theta_i)}]}{r}, \tag{21}$$

where T is the seller's optimal time for putting the asset into production use, which may not coincide with the expiration date set out in the contract specifications ($T \leq \overline{T}$).

Allocating the contract on the basis of the highest instantaneous score, $s(\theta_i)$, might therefore not be the best choice for the buyer, since the most efficient bidder could be more prone than others to early exit. This becomes clear if we take a closer look at the derivative of Eq. (15.1) with respect to the bidders' types:

$$\frac{dp^*(\theta_i)}{d\theta_i} = -\frac{\beta}{\beta - 1}(\Delta_\theta(\theta_i) + \frac{ds(\theta_i)}{d\theta_i}). \tag{22}$$

Since $\Delta_\theta(\theta_i) < 0$ and $ds(\theta_i)/d\theta_i > 0$, the sign of $dp^*(\theta_i)/d\theta_i$ is ambiguous. In other words, higher values of θ can either translate into an increase, or a reduction of the optimal trigger for breaching the contract. In the latter case, the combination of high instantaneous net benefits and a short service period can turn out not being the one giving the buyer the highest total payoff.

5.1 Accounting for the risk of opportunistic behavior

The risk of not selecting the agent providing the highest potential payoff could be avoided if the buyer: (i) exploited the information gathered through the bidding process and (ii) used the total expected payoff, $S(\theta_i)$, rather than the instantaneous score, $s(\theta_i)$, to allocate the contract.

This would come at no cost in terms of auction efficiency, as long as we make the following assumption on information rents.

■ **Assumption 6:** $-\Delta_\theta(\theta_i)(F(\theta_i)/f(\theta_i))$ is increasing in θ_i and is bounded above by $(n - 1)/[(1 - E_0[e^{-rT_i(\theta_i)}])/r]$ for each $\theta_i \in [\theta^l, \theta^u]$

Notice that if $\Delta(\theta_i) \equiv [c(g, \theta_i) - rK(\theta_i)]$ is concave in θ_i, Assumption 1 would suffice for having $-\Delta_\theta(\theta_i)(F(\theta_i)/f(\theta_i))$ increasing in θ_i (see, for example, Guesnerie and Laffont, 1984). However, in our dynamic frame, the standard assumption about the hazard rate does not ensure the monotonicity of $T(\theta_i)$ and, therefore, the monotonicity of $S(\theta_i)$, since information rents for the most efficient agents might be so high that they can competitively bid on the instantaneous score and win the auction, even though there might be other bidders able to ensure, as a whole, higher total benefits to the buyer.

This therefore calls for a restriction on the speed at which informational rents grow. For instance, by rearranging equation Eq. (22) as follows (see Appendix A.4):

$$\frac{dp^*(\theta_i)}{d\theta_i} = \frac{\beta}{\beta - 1}\Delta_\theta(\theta_i)[(n-1)\frac{f(\theta_i)}{F(\theta_i)}\frac{W(\theta_i)}{dW(\theta_i)/d\theta_i} - 1] \tag{22.1}$$

it can be noticed that a sufficient condition for $dp^*(\theta_i)/d\theta_i > 0$ is that:

$$\Delta_\theta(\theta_i)\frac{1 - E_0[e^{-rT_i(\theta_i)}]}{r}F^{(n)}(\theta_i) + f^{(n)}(\theta_i) > 0 \text{ for all } \theta_i \in [\theta^l, \theta^u]$$

which is ensured by Assumption 6.

The following proposition captures this result.

Proposition 4 *Under Assumption 6, for any finite n it will always exist an equilibrium in symmetric strictly increasing strategies $s(\theta_i)$ with a non-decreasing optimal expected service period in θ_i, that is, $dS(\theta_i)/d\theta_i > 0$.*

Proof. See Appendix A.4. ■

It is worth notice that the regularity condition imposed by Assumption 6 is a sufficient (not necessary) condition for the equilibrium existence. For instance, should the condition not be met in a subset of the space $[\theta^l, \theta^u]$, the solution in Proposition 2 could still constitute an equilibrium, since there can be a value $\hat{\theta} \in [\theta^l, \theta^u]$ beyond which, despite $dp^*(\theta_i)/d\theta_i \leq 0$, $dS(\theta_i)/d\theta_i > 0$ for every $\theta_i \in [\theta^l, \theta^u]$ (see Appendix A.4). In this case, even though not ensuring the longest service provision, the least-cost agent will provide the buyer with the highest payoff, by compensating the shortening of service period with higher instantaneous benefits.

5.2 An example

The following example illustrates the role played by eligibility rules and the degree of competition in ensuring a sufficient condition for, as described in Proposition 4, the existence of an equilibrium.

Suppose that the sunk cost for developing L for production use is $K(\theta) = \theta^u - \theta$, the cost of environmental proactivity is $c(g, \theta) = (g^2/2) - g(\theta - \theta^l)$, and the instantaneous social benefits arising from conservation practices are $v(g) = g$. For the sake of simplicity, we assume that the agent-types are uniformly distributed between 0 and 1, that is, $F(\theta) = \theta$ and $f(\theta) = 1$.

Thus, by Eq. (10), we get:

$$g(\theta) = 1 + \theta \geq 1 \tag{23}$$

As shown in Appendix A.4, for the case of a trendless geometric Brownian motion, Assumption 6 is implied by the following condition:

$$\Delta_\theta(\theta)(F(\theta)/f(\theta)) > r(n-1) \tag{24}$$

where $\Delta_\theta(\theta) = r - g(\theta) < 0$ is decreasing in θ. Substituting Eq. (23) into condition (24) and rearranging we obtain:

$$Q(\theta; n) \equiv (1 + \theta - r)\theta - r(n-1) < 0 \tag{24.1}$$

Notice that, for any n, $Q(\theta; n)$ is increasing in θ in the interval $[0, 1]$, with $Q(0) = -r(n-1)$ and $Q(1) = 2 - rn$.

Denoting by $\overleftrightarrow{\theta}$ the solution of the equation $Q(\overleftrightarrow{\theta}; n) = 0$, this is given by:

$$\overleftrightarrow{\theta} = \sqrt{\left(\frac{1-r}{2}\right)^2 + r(n-1)} - \frac{1-r}{2}$$

where $\overleftrightarrow{\theta} \geq 1$ for $n \geq 2/r$.

Hence, as long as the number of bidders is relatively high ($n \geq 2/r$), no restrictions on the eligibility rules are needed in order to ensure that $dS(\theta_i)/d\theta_i > 0$ over the entire range $[0, 1]$. However, if competition is relatively low ($n < 2/r$), the buyer could get a higher pay-off by restricting the range of eligible agents, namely by excluding from award bidders belonging to the subset $[\overleftrightarrow{\theta}, 1]$.

6 Final remarks

Contracts providing payments for environmental services generally require long-term commitments. Landowners, however, could find it profitable to breach the contract when the cost of complying with conservation requirements increases. While this does not necessarily have to lead to early exit, this possibility can be exacerbated by the lack of incentives against contract breach. The question addressed in the paper is how this can affect bidding behavior and the parties' individual payoffs in auctions where sellers are selected on the basis of both the promised conservation practices and the required rental payments.

The novelty of our model, with respect to the previous literature on scoring auctions, is that agents can adjust their bidding strategies by exploiting the managerial flexibility spurred by the lack of incentives against contract infringements. This implies that, unlike when the project deadline is enforceable, agents' bidding strategies will be affected by endogenous timing considerations.

A first result of the paper is that the managerial flexibility does not translate into higher expected payoffs for the sellers. This is because, in a competitive environment, the potential benefits, stemming the opportunity to terminate the contract, are outweighed by the stronger bid competition spurred by the lack of enforcement of contract terms. Thus, besides increasing the risk of failure of conservation programs, the weak enforcement of contract requirements may not even be in the sellers' best interest.

A second result is that failure to account for the risk of opportunistic behavior could lead to the choice of sellers who will not provide the buyer with the highest potential payoff. This possibility relies on the correlation between the cost of undertaking conservation activities and the opportunity cost of not exploiting land for commercial uses. If costs are negatively correlated, that is, if agents that are able to more efficiently exploit the asset for commercial use are also able to undertake conservation activities at lower costs, the most efficient bidders, while providing the buyer with the highest instantaneous net benefits, can be more prone than others to early exit. Hence, the combination of higher instantaneous payoffs and shorter service periods can turn out not being the one giving the buyer the highest total value.

The paper makes suggestions which may contribute to avoid such potential bias in contract allocation. We argued that, when contracting agencies cannot rely on sufficiently strong incentives against non-compliance, they should internalize the risk of early exit, by exploiting the information gathered through the auction process in order to assess, and include in bid evaluation, the bidders' actual prospective compliance. This would not affect the auction's allocative efficiency, so long as the number of bidders is sufficiently high to downsize the most efficient agents' information rents. Otherwise, if competition is relatively low, it might be profitable for the buyer to restrict the range of eligible agents, by excluding from award bidders with relatively high opportunity costs of compliance with conservation requirements.

A Appendix

A.1 Proposition 1

In spite of being quite standard in the auction literature, we include the following proof for the reader's convenience. Consider a common prior cumulative distribution $F(\theta)$ with continuously differentiable density $f(\theta)$ defined on a positive support $\Theta = [\theta^l, \theta^u] \subseteq R_+$, where the lowest value θ^l is such that $\theta^l = \inf[\theta : f(\theta) > 0]$ and the highest value is $\theta^u = \sup[\theta : f(\theta) > 0]$. Now consider the agent i's bidding behavior. It is immediate to note that the maximization of the objective in (9) is equivalent to maximize the instantaneous expected net payoff, i.e. $[(b_i - c(g_i, \theta_i)) -$

$(p_0 - rK(\theta_i))]\Pr(\text{of win}/s_i)$, and that $(b_i - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))$ must be non-negative to guarantee a positive expected payoff (otherwise, winning the auction would never be profitable). Assume that all other bidders use a strictly monotone increasing bid function $s(\theta_j)$, i.e., $s(\theta_j) : [\theta^l, \theta^u] \to [s(\theta^u), s(\theta^l)]\ \forall j \neq i$. Since, by assumption, $s(\theta_i)$ is monotone in $[\theta^l, \theta^u]$, the probability of winning by bidding $s(\theta_i)$ is $\Pr(s(\theta_i) > s(\theta_j) \mid \forall j \neq i) = \Pr(\theta_j < s^{-1}(s(\theta_i)) \mid \forall j \neq i) = F(s^{-1}(s(\theta_i)))^{n-1} = F(\theta_i)^{n-1} \equiv F^{(n)}(\theta_i)$.

The type reported, $\tilde{\theta}_i$, by agent θ_i solves the following problem:

$$\begin{aligned}\bar{W}(\theta_i, \tilde{\theta}_i) &= \max_{\tilde{\theta}}[(b(\tilde{\theta}_i) - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - e^{-r\overline{T}}}{r}\Pr(\text{of win}/s_i) \\ &= \max_{\tilde{\theta}}[(b(\tilde{\theta}_i) - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - e^{-r\overline{T}}}{r}F^{(n)}(\tilde{\theta}_i),\end{aligned}$$

where, by Che (1993, Lemma 1, p. 672), $g_i \equiv g(\tilde{\theta}_i)$ is determined by Eq. (10). This in turn implies that:

$$\bar{W}(\theta_i, \tilde{\theta}_i) = \max_{\tilde{\theta}}[(b(\tilde{\theta}_i) - c(g(\tilde{\theta}_i), \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - e^{-r\overline{T}}}{r}F^{(n)}(\tilde{\theta}_i), \tag{A.1.1}$$

Maximizing (A.1.1) and imposing the truth-telling condition $\tilde{\theta}_i = \theta_i$ yield the following necessary condition:

$$\begin{aligned}\frac{\partial \bar{W}(\theta_i, \tilde{\theta}_i)}{\partial \tilde{\theta}_i} \mid_{\tilde{\theta}_i = \theta_i} &= (\frac{db(\theta_i)}{d\theta_i} - c_g(g(\theta_i), \theta_i)\frac{dg(\theta_i)}{d\theta_i})F^{(n)}(\theta_i) + \\ &+[(b(\theta_i) - c(g(\theta_i), \theta_i)) - (p_0 - rK(\theta_i))]f^{(n)}(\theta_i) = 0\end{aligned}$$

or

$$(\frac{db(\theta_i)}{d\theta_i} - c_g(g(\theta_i), \theta_i)\frac{dg(\theta_i)}{d\theta_i})F^{(n)}(\theta_i) = -[(b(\theta_i) - c(g(\theta_i), \theta_i)) - (p_0 - rK(\theta_i))]f^{(n)}(\theta_i). \tag{A.1.1b}$$

Integrating Eq. (A.1.1b) on both sides yields:

$$\int_{\theta^l}^{\theta_i}(\frac{db(x)}{d\theta_i} - c_g(g(x), x)\frac{dg(x)}{d\theta_i})F^{(n)}(x)dx = -\int_{\theta^l}^{\theta_i}[(b(x) - c(g(x), x)) - (p_0 - rK(x))]f^{(n)}(x)dx$$

Using integration by parts, one can easily show that:

$$\bar{b}(\theta_i) = c(g(\theta_i), \theta_i) + (p_0 - rK(\theta_i)) - \int_{\theta^l}^{\theta_i}\Delta_\theta(x)\frac{F^{(n)}(x)}{F^{(n)}(\theta_i)}dx, \tag{A.1.2}$$

where $\Delta_\theta(x) = c_\theta(g(x), x) - rK_\theta(x) < 0$ for $x \in [\theta^l, \theta_i]$.

Eq. (A.1.2) can be used in order to define the agent's expected payoff. That is:

$$\bar{W}(\theta_i) = -\int_{\theta^l}^{\theta_i}\Delta_\theta(x)\frac{1 - e^{-r\overline{T}}}{r}F^{(n)}(x)dx + \bar{W}(\theta^l)\frac{1 - e^{-r\overline{T}}}{r}, \tag{A.1.3}$$

where, by Eq. (8), $\bar{W}(\theta^l) = 0$. Finally, by differentiating Eq. (A.1.2) with respect to θ_i and rearranging, we obtain:

$$\frac{d\bar{b}(\theta_i)}{d\theta_i} = c_g(g(\theta_i), \theta_i)\frac{dg(\theta_i)}{d\theta_i} + (n-1)\frac{f(\theta_i)}{F(\theta_i)}\int_{\theta^l}^{\theta_i}\Delta_\theta(x)\frac{F^{(n)}(x)}{F^{(n)}(\theta_i)}dx. \tag{A.1.4}$$

Eq. (A.1.4) implies that $\bar{b}(\theta_i)$ is increasing in the cost of producing higher quality, $g(\theta_i)$, and decreasing in the information rent, i.e. $-\int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx$, to be paid.

By differentiating Eq. (2) with respect to θ_i and using Eq. (10) and Eq. (A.1.4), we can immediately prove the assumed monotonicity of the optimal strategy $\bar{s}(\theta^i)$:

$$\frac{d\bar{s}(\theta_i)}{d\theta_i} = -(n-1)\frac{f(\theta_i)}{F(\theta_i)} \int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx > 0. \tag{A.1.5}$$

Finally, by using Eq. (A.1.5), we can easily prove the auction efficiency. That is

$$\frac{d\overline{S}(\theta_i)}{d\theta_i} = \frac{d\bar{s}(\theta_i)}{d\theta_i} \frac{1 - e^{-r\overline{T}}}{r} > 0. \tag{A.1.6}$$

This concludes the proof.

A.2 Proposition 2

Separability - Let's first show that the following lemma holds:

Lemma 1 *With a first-score auction, the equilibrium good quality, $g(\theta_i)$, is chosen such that*

$$g(\theta_i) = \arg\max \left[v(g_i) - c(g_i, \theta_i) \right], \text{ for all } \theta_i \in [\theta^l, \theta^u]. \tag{A.2.1}$$

This lemma can be easily shown by adapting to our case the proof provided by Che (1993, Lemma 1). Suppose that any equilibrium bid, (b_i, g_i), with $g_i \neq g(\theta_i)$, is dominated by an alternative bid, (b_i', g_i') where $b_i' = b_i + v(g_i') - v(g_i)$, and $g_i' = g(\theta_i)$. It follows that:

$$\begin{aligned} b_i - c(g_i, \theta_i) &= b_i' - c(g_i', \theta_i) + \left[(v(g_i) - c(g_i, \theta_i)) - (v(g_i') - c(g_i', \theta_i)) \right] \\ &< b_i' - c(g_i', \theta_i), \end{aligned} \tag{A.2.2}$$

which in turn implies $p^*(b_i, g_i, \theta_i) < p^{*\prime}(b_i', g_i', \theta_i)$ and $E_0\left[e^{-rT_i}\right] > E_0[e^{-rT_i'}]$.

Given Eq. (A.2.2), it can be easily shown that

$$S_i = (v(g_i) - b_i)\frac{1 - E_0[e^{-rT_i}]}{r} = (v(g_i') - b_i')\frac{1 - E_0[e^{-rT_i}]}{r} < (v(g_i') - b_i')\frac{1 - E_0[e^{-rT_i'}]}{r} = S_i', \tag{A.2.3}$$

or, equivalently, that Pr(of win/S_i') > Pr(of win/S_i). Note also that $\Pi(b_i, g_i; \theta_i) - \widehat{\Pi}(\theta_i)$ (see Eq. (16)) is increasing in $h(b_i, g_i, \theta_i) = b_i - c(g_i, \theta_i)$ as:

$$\frac{\partial[\Pi(S_i) - \Pi(0, 0; \theta_i)]}{\partial h} = \frac{1 - (\frac{p_0}{p^*})^\beta (\frac{dp^*}{dh}\frac{h}{p^*})}{r} > 0.$$

This in turn implies that:

$$\begin{aligned} W(b_i, g_i; \theta_i) &= \{[(b_i - c(g_i, \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - E_0[e^{-rT_i}]}{r} + (p^* - p_0)\frac{E_0[e^{-rT_i}]}{r}\} \Pr(\text{of win}/S_i) \\ &< \{[(b_i' - c(g_i', \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - E_0[e^{-rT_i'}]}{r} + (p^{*\prime} - p_0)\frac{E_0[e^{-rT_i'}]}{r}\} \Pr(\text{of win}/S_i') \\ &= W(b_i', g_i', \theta_i). \end{aligned} \tag{A.2.4}$$

Finally, given Lemma 1, the equilibrium quality, $g(\theta_i)$, can be determined using a standard set of optimality conditions. Note that the problem is equivalent to (10). Hence, the same set of first- and second-order conditions holds also in this case (see condition (10.1)).

Bayes-Nash equilibrium - Let's now consider agent i's bidding behavior. Assume that all other bidders use a strictly monotone increasing bid function $s(\theta_j)$, i.e., $s(\theta_j) : [\theta^l, \theta^u] \to [s(\theta^u), s(\theta^l)]\ \forall j \neq i$. Since, by assumption, $s(\theta_i)$ is monotone in $[\theta^l, \theta^u]$, the probability of winning by bidding $s(\theta_i)$ is $\Pr(s(\theta_i) > s(\theta_j) \mid \forall j \neq i) = \Pr(\theta_j < s^{-1}(s(\theta_i)) \mid \forall j \neq i) = F(s^{-1}(s(\theta_i)))^{n-1} = F(\theta_i)^{n-1} \equiv F^{(n)}(\theta_i)$.

It follows that agent i chooses his report $\tilde{\theta}_i$ by solving the following problem:

$$W(\theta_i, \tilde{\theta}_i) = \max_{\tilde{\theta}}\{[(b(\tilde{\theta}_i) - c(g(\tilde{\theta}_i), \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - E_0[e^{-rT_i(\tilde{\theta}_i,\theta_i)}]}{r} +$$
$$+(p^*(\tilde{\theta}_i, \theta_i) - p_0)\frac{E_0[e^{-rT_i(\tilde{\theta}_i,\theta_i)}]}{r}\} \Pr(\text{of win}/s_i)$$
$$= \max_{\tilde{\theta}}\{[(b(\tilde{\theta}_i) - c(g(\tilde{\theta}_i), \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - E_0[e^{-rT_i(\tilde{\theta}_i,\theta_i)}]}{r} +$$
$$+(p^*(\tilde{\theta}_i, \theta_i) - p_0)\frac{E_0[e^{-rT_i(\tilde{\theta}_i,\theta_i)}]}{r}\} \Pr(s(\tilde{\theta}_i) < \max_{j\neq i} s(\theta_j))$$
$$= \max_{\tilde{\theta}}\{[(b(\tilde{\theta}_i) - c(g(\tilde{\theta}_i), \theta_i)) - (p_0 - rK(\theta_i))]\frac{1 - E_0[e^{-rT_i(\tilde{\theta}_i,\theta_i)}]}{r} +$$
$$+(p^*(\tilde{\theta}_i, \theta_i) - p_0)\frac{E_0[e^{-rT_i(\tilde{\theta}_i,\theta_i)}]}{r}\}F^{(n)}(\tilde{\theta}_i), \tag{A.2.5}$$

where, by Lemma 1, $g_i \equiv g(\tilde{\theta}_i)$ is still determined by solving Eq. (10).

In order to derive the equilibrium strategies we could solve the ordinary differential equation that follows from the maximization problem in Eq. (A.2.5). However, differently from the problem in Eq. (A.1.1), this ordinary differential equation, due to the presence of the optimal trigger $p^*(\tilde{\theta}_i, \theta_i)$ (and the stopping time $T_i(\tilde{\theta}_i, \theta_i)$), does not have a closed-form solution. We then determine the integral equation that describe the utility $W(\theta_i)$ by using the generalized Envelope Theorem provided by Milgrom and Segal (2002, Theorem 2).[22]

Suppose that each agent sets $y \in Y$ to maximize $\psi(y, \omega)$, where $\omega \in [0, 1]$ and Y is arbitrary. Denote the set of maximizers by $\overline{y}(\omega) := \arg\max_y \psi(y, \omega)$ and let $\Psi(\omega) = \sup_{y\in Y} \psi(y, \omega)$.

Lemma 2 *(Milgrom and Segal, 2002, Theorem 2). Suppose a) $\psi(y, \omega)$ is differentiable and absolutely continuous in ω (∇y); (b) $|\partial\psi(y, \partial\omega)|$ is uniformly bounded $(\nabla y)(\nabla\omega)$, and (c) $\overline{y}(\omega)$ is nonempty. Then, for any selection $y^*(\omega) \in \overline{y}(\omega)$,*

$$\Psi(\omega) = \int_0^\omega \partial\psi(y^*(x), x)\partial\omega dx + \Psi(0). \tag{A.2.6}$$

Now, let set $\omega = \theta_i$ and $y = (\tilde{\theta}_i, T_i)$ (or equivalently $(\tilde{\theta}_i, p_i^*)$), and apply Milgrom and Segal's theorem to the problem in Eq. (A.2.5). Note that: (i) $W(\theta_i, \tilde{\theta}_i)$ is always differentiable and continuous in θ_i; (ii) the derivative of W is bounded because of Assumption 1; (iii) Eq. (15.1) says that the stopping time attains its maximum for given b_i and θ_i. Since, by the revelation principle, $\tilde{\theta}_i = \theta_i$, it follows that:

$$W(\theta_i) = -\int_{\theta^l}^{\theta_i} \Delta_\theta(x)\frac{1 - E_0[e^{-rT_i(x)}]}{r}F^{(n)}(x)dx + W(\theta^l), \tag{A.2.7}$$

where, by Eq. (8), $W(\theta^l) = 0$.

[22] See Board (2007, p. 329) for a similar application.

Now, we can use Eq. (A.2.7) in order to define the equilibrium payment. The equilibrium payment, $b(\theta_i)$, solves the following implicit equation:

$$[(b(\theta_i) - c(g(\theta_i), \theta_i)) - (p_0 - rK(\theta_i))] \frac{1 - E_0[e^{-rT_i(\theta_i)}]}{r} + \\ +(p^*(\theta_i) - p_0) \frac{E_0[e^{-rT_i(\theta_i)}]}{r} = -\int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{1 - E_0[e^{-rT_i(x)}]}{r} \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx, \tag{A.2.8}$$

which can be rearranged as in Eq. (19). Although it is not possible to express $b(\theta_i)$ in a closed form, we may easily show some of its properties. In fact, by totally differentiating Eq. (A.2.8) with respect to θ_i and rearranging, we obtain

$$\frac{db(\theta_i)}{d\theta_i} = c_g(g(\theta_i), \theta_i) \frac{dg(\theta_i)}{d\theta_i} + (n-1) \frac{f(\theta_i)}{F(\theta_i)} \frac{\int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{1 - E_0[e^{-rT_i(x)}]}{r} \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx}{\frac{1 - E_0[e^{-rT_i(\theta_i)}]}{r}}. \tag{A.2.9}$$

We notice that the payment, $b(\theta_i)$, is increasing in the cost of producing higher quality and decreasing in the information rent to be paid. Finally, by using Eq. (A.2.9), it is easy to show that the bid function $s(\theta_i)$ is strictly monotone and increasing in θ_i:

$$\frac{ds(\theta_i)}{d\theta_i} = -(n-1) \frac{f(\theta_i)}{F(\theta_i)} \frac{\int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{1 - E_0[e^{-rT_i(x)}]}{r} \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx}{\frac{1 - E_0[e^{-rT_i(\theta_i)}]}{r}} > 0. \tag{A.2.10}$$

It remains to show that Eq. (A.2.7) provides the unique local maximum for the problem in Eq. (A.2.5). As usual, the uniqueness follows from the fact that the function in Eq. (A.2.7) is increasing in θ_i and has Eq. (8) as boundary condition. For showing that it is a maximum, it suffices to prove that s_i is incentive compatible:

$$W(\theta_i, \theta_i) \geq W(\theta_i, \tilde{\theta}_i), \tag{A.2.11}$$

for all $(\theta_i, \tilde{\theta}_i) \in [\theta^l, \theta^u] \times [\theta^l, \theta^u]$. We prove this by following the approach in adopted by Milgrom (2004, Ch.4).

Lemma 3. *The equilibrium strategy $s(\theta_i)$ is incentive compatible if and only if equation (A.2.7) holds and if $s(\theta_i)$ is strictly increasing.*

Necessity. Since $s(\theta_i)$ is strictly increasing then by the Monotonic Selection Theorem (Milgrom, 2004, Theorem 4.1), the function $W(\theta_i, \tilde{\theta}_i)$ satisfies the strict single-crossing difference condition.

Sufficiency. Suppose that $W(\theta_i, \tilde{\theta}_i)$ satisfies the strict-single crossing difference condition. If $s(\theta_i)$ is strictly increasing and Eq. (A.2.7) holds then by the Sufficient Theorem (Milgrom, 2004, Theorem 4.2), $s(\theta_i)$ is a local maximum for the problem in Eq. (A.2.5).

This concludes the proof.

A.3 Proposition 3

By rearranging Eq. (19) we obtain:

$$b(\theta_i) = c(g(\theta_i), \theta_i) + (p_0 - rK(\theta_i)) - \int_{\theta^l}^{\theta_i} \Delta_\theta(x) \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx - M(\theta_i) = \bar{b}(\theta_i) - M(\theta_i), \tag{A.3.1}$$

where $M(\theta_i) = \frac{-\int_{\theta^l}^{\theta_i} \Delta_\theta(x)(E_0[e^{-rT_i(x)}] - E_0[e^{-rT_i(\theta_i)}]) \frac{F^{(n)}(x)}{F^{(n)}(\theta_i)} dx + E_0[e^{-rT_i(\theta_i)}](p^*(\theta_i) - p_0)}{1 - E_0[e^{-rT_i(\theta_i)}]}$.

Now, note that:

$$p^*(\theta_i) - p_0 = \overline{p}^*(\theta_i) - p_0 - \frac{\beta}{\beta-1}M(\theta_i), \quad \text{(A.3.2)}$$

where $\overline{p}^*(\theta_i) = \frac{\beta}{\beta-1}(\bar{b}(\theta_i) - c(g(\theta_i),\theta_i) + rK(\theta_i)) = \frac{\beta}{\beta-1}(p_0 - \int_{\theta^l}^{\theta_i}\Delta_\theta(x)\frac{F^{(n)}(x)}{F^{(n)}(\theta_i)}dx)$.

Substituting Eq. (A.3.2) into $M(\theta_i)$ yields:

$$M(\theta_i) = -\frac{(\beta-1)\int_{\theta^l}^{\theta_i}\Delta_\theta(x)E_0[e^{-rT_i(x)}]dx - E_0[e^{-rT_i(\theta_i)}]\overline{p}^*(\theta_i)}{(\beta-1)+E_0[e^{-rT_i(\theta_i)}]} > 0. \quad \text{(A.3.4)}$$

This in turn implies that:

$$b(\theta_i) < \bar{b}(\theta_i), \quad \text{(A.3.5)}$$
$$p^*(\theta_i) < \overline{p}^*(\theta_i). \quad \text{(A.3.6)}$$

It follows that:

$$s(\theta_i) = (v(g(\theta_i) - b(\theta_i)) > (v(g(\theta_i) - \bar{b}(\theta_i))) = \bar{s}(\theta_i). \quad \text{(A.3.7)}$$

Finally, by direct inspection of $\Delta_\theta(x)(1 - E_0[e^{-rT_i(x)}])$ and $\Delta_\theta(x)(1-e^{-r\overline{T}})$, it is also immediate to show that if $T_i(x) > \overline{T}$

$$W(\theta_i) > \bar{W}(\theta_i). \quad \text{(A.3.8)}$$

This concludes the proof.

A.4 Proposition 4

By deriving $p^*(\theta_i)$ with respect to θ_i we obtain:

$$\frac{dp^*(\theta_i)}{d\theta_i} = -\frac{\beta}{\beta-1}(\Delta_\theta(\theta_i) + \frac{ds(\theta_i)}{d\theta_i}). \quad \text{(A.4.1)}$$

As can be easily seen, substituting for $ds(\theta_i)/d\theta_i$ yields

$$\begin{aligned}\frac{dp^*(\theta_i)}{d\theta_i} &= \frac{\beta}{\beta-1}[-\Delta_\theta(\theta_i) + (n-1)\frac{f(\theta_i)}{F(\theta_i)}\frac{\int_{\theta^l}^{\theta_i}\Delta_\theta(x)\frac{1-E_0[e^{-rT_i(x)}]}{r}\frac{F^{(n)}(x)}{F^{(n)}(\theta_i)}dx}{\frac{1-E_0[e^{-rT_i(\theta_i)}]}{r}}] \\ &= \frac{\beta}{\beta-1}\Delta_\theta(\theta_i)[(n-1)\frac{f(\theta_i)}{F(\theta_i)}\frac{W(\theta_i)}{dW(\theta_i)/d\theta_i} - 1] \quad \text{(A.4.2)}\end{aligned}$$

Since $[\beta/(\beta-1)]\Delta_\theta(\theta_i) < 0$, it follows that $dp^*(\theta_i)/d\theta_i > 0$ when the term into square brackets in Eq. (A.4.2) is positive or, equivalently, if:

$$W(\theta_i) < F^{(n)}(\theta_i) \quad \text{(A.4.3)}$$

Rearranging condition (A.4.3), we obtain:

$$-\int_{\theta^l}^{\theta_i}(\Delta_\theta(x)\frac{1-E_0[e^{-rT_i(x)}]}{r}F^{(n)}(x) + f^{(n)}(x))dx < 0 \quad \text{(A.4.4)}$$

which, by Assumption 6, is always satisfied. Further, note that, by the Jensen's inequality, $E_0[e^{-rT_i(x)}] > e^{-rE_0[T_i(x)]}$. This implies that:

$$\frac{n-1}{\frac{1-E_0[e^{-rT_i(x)}]}{r}} > \frac{n-1}{\frac{1-e^{-rE_0[T_i(x)]}}{r}}$$

This means that Assumption 6 is implied by the following condition:

$$-\Delta_\theta(x)(F(x)/f(x)) < \frac{n-1}{\frac{1-e^{-rE_0[T_i(x)]}}{r}}$$

which, for the case of a trendless geometric Brownian motion, reduces to:[23]

$$-\Delta_\theta(x)(F(x)/f(x)) < r(n-1) \tag{A.4.5}$$

Let's now check the properties of the scoring rule $S(\theta_i)$. We notice that:

$$\frac{dS(\theta_i)}{d\theta_i} = \frac{ds(\theta_i)}{d\theta_i}\frac{1-E_0[e^{-rT_i(\theta_i)}]}{r} - \frac{s(\theta_i)}{r}\frac{dE_0[e^{-rT_i(\theta_i)}]}{dp^*(\theta_i)}\frac{dp^*(\theta_i)}{d\theta_i}. \tag{A.4.6}$$

This implies that $S(\theta_i)$ is increasing in θ_i when the following condition holds:

$$(n-1)\frac{f(\theta_i)}{F(\theta_i)} > \beta\frac{\frac{s(\theta_i)}{\theta_i}}{\int_{\theta^l}^{\theta_i}\Delta_\theta(x)\frac{1-E_0[e^{-rT_i(x)}]}{r}\frac{F^{(n)}(x)}{F^{(n)}(\theta_i)}dx}\frac{E_0[e^{-rT_i(\theta_i)}]}{r}(\frac{dp^*(\theta_i)}{d\theta_i}\frac{\theta_i}{p^*(\theta_i)}). \tag{A.4.7}$$

This condition is always satisfied for $dp^*(\theta_i)/d\theta_i > 0$.

We conclude by highlighting that $dp^*(\theta_i)/d\theta_i \geq 0$ is only a sufficient (not necessary) condition for the existence of the equilibrium, i.e., $S(\theta_i)$ monotone in θ_i. By direct inspection of Eq. (A.4.2), the sign of $dp^*(\theta_i)/d\theta_i$ depends on:

$$\text{sign}(\frac{dp^*(\theta_i)}{d\theta_i}) = \text{sign}[-\frac{f(\theta_i)}{F(\theta_i)}\int_{\theta^l}^{\theta_i}F^{(n)}(x)d(\Delta_\theta(x)\frac{1-E_0[e^{-rT_i(x)}]}{r}\frac{F(x)}{f(x)})dx] > 0. \tag{A.4.8}$$

Since, by Assumption 6, $-\Delta_\theta(x)\frac{1-E_0[e^{-rT_i(x)}]}{r}(F(x)/f(x))$ is increasing, there exists $\theta^l \leq \xi \leq \theta_i$ such that:

$$\text{sign}(\frac{dp^*(\theta_i)}{d\theta_i}) = \text{sign}[\frac{f(\theta_i)}{F(\theta_i)}F^{(n)}(\theta_i)(\Delta_\theta(\xi)\frac{1-E_0[e^{-rT_i(\xi)}]}{r}\frac{F(\xi)}{f(\xi)} - \Delta_\theta(\theta_i)\frac{1-E_0[e^{-rT_i(\theta_i)}]}{r}\frac{F(\theta_i)}{f(\theta_i)})] \tag{A.4.9}$$

from which it follows that $\lim_{\theta_i > \xi \to \theta^l,} dp^*(\theta_i)/d\theta_i > 0$. Thus, even if it may exist a value of $\hat{\theta}$ beyond which $dp^*(\theta_i)/d\theta_i \leq 0$, $S(\theta_i)$ is still increasing for all $\theta_i \in [\theta^l, \theta^u]$.

This concludes the proof.

[23] By (1), $E_0[T_i(x)] = \infty$. See (Dixit, 1993, pp. 54-57).

References

[1] Asker, J., Cantillon, E., (2010), Procurement when price and quality matter, *RAND Journal of Economics,* 41, 1, 1-34.

[2] Board, S., (2007). Selling options, *Journal of Economic Theory*, 136, 1, 324-340.

[3] Che, Y.K., (1993). Design competition through multidimensional auctions, *RAND Journal of Economics*, 24, 4, 668-680.

[4] Claassen, R., Cattaneo, A. and Johansson, R., (2008). Cost-effective design of agri-environmental payment programs: U.S. experience in theory and practice, *Ecological Economics*, 65, 4, 737–752.

[5] Cummings, R.C., Holt, C.A. and Laury, S., (2003). Using Laboratory Experiments for Policy Making: An Example from the Georgia Irrigation Reduction Auction. Andrew Young School of Policy Studies Research Paper Series No. 06-14. Available at SSRN: http://ssrn.com/abstract=893800 (accessed 05 May 2014).

[6] DiMatteo, L.A., (2001). A Theory of Efficient Penalty: Eliminating the Law of Liquidated Damages, *American Business Law Journal*, 38, 4 633-733.

[7] Dixit, A., and Pindyck, R., (1994). *Investment under Uncertainty*. Princeton University Press, Princeton.

[8] Dixit, A., (1993).*The Art of Smooth Pasting*. Fundamentals of Pure and Applied Economics 55, London and New York: Routledge.

[9] Dosi, C., Moretto, M., (2013). Procurement with enenforceable contract time and the law of liquidated damages, *Journal of Law, Economics, & Organization*, 31, doi:10.1093/jleo/ewt020.

[10] European Economic Community (EEC), (1988). Commission Regulation (EEC) No 1272/88 of 29 April 1988 laying down detailed rules for applying the set-aside incentive scheme for arable land, *Official Journal of the European Communities*, L121/36–40.

[11] Espinosa-Arredondo, A., (2008). Green auctions: A biodiversity study of mechanism design with externalities, *Ecological Economics*, 67, 175-183.

[12] Ferraro, P.J., (2008). Asymmetric information and contract design for payments for environmental services, *Ecological Economics*, 65, 4, 810-821.

[13] Giannakas, K., Kaplan, J., (2005). Policy Design and Conservation Compliance on Highly Erodible Lands, *Land Economics*, 81, 1, 20-33.

[14] Gibbons, J., Nicholson, E., Milner-Gulland, E.J., and Jones, J., (2011). Should Payments for Biodiversity Conservation be Based on Action or Results?, *Journal of Applied Ecology*, 48, 1218-1226.

[15] Goetz, C., Scott, R., (1977). Liquidated Damages, Penalties, and the Just Compensation Principle: Some Notes in an Enforcement Model of Efficient Breach, *Columbia Law Review*, 77, 4, 554-594.

[16] Gulati, S., Vercammen, J., (2006). Time inconsistent resource conservation contracts, *Journal of Environmental Economics and Management*, 52, 1, 454-468.

[17] Hart, R., Latacz-Lohmann, U., (2005). Combating Moral Hazard in Agri-Environmental Schemes: A Multiple-Agent Approach, *European Review of Agricultural Economics,* 32, 1, 75–91.

[18] Kelman, S., (1990). *Procurement and Public Management: The Fear of Discretion and the Quality of Government Performance*, Washington D.C.: The AEI Press.

[19] Kirwan, B., Lubowski, R.N., and Roberts, M.J. (2005). How cost-effective are land retirement auctions? Estimating the difference between payments and willingness to accept in the Conservation Reserve Program, *American Journal of Agricultural Economics*, 87, 5, 1239-1247.

[20] Krishna, V. (2009), *Auction theory*, Academic Press, San Diego.

[21] Larkin, S.L., Keithly, W., Adams, C.M. and Waters, J., (2004). Buyback programs or capacity reduction in the U.S. shark fishery, *Agricultural and Applied Economics*, 36, 2, 317-332.

[22] Latacz-Lohmann, U., Schilizzi, S., (2005). Auctions for Conservation Contracts: A Review of the Theoretical and Empirical Literature. Report to the Scottish Executive Environment and Rural Affairs Department. Available at http://scotland.gov.uk/Resource/Doc/93853/0022574.pdf (accessed 05 May 2014).

[23] Lo, W., Lin, C. L., Yan, M. R., (2007). Contractor's Opportunistic Bidding Behavior and Equilibrium Price Level in the Construction Market, J*ournal of Construction Engineering and Management*, 133, 6, 409-416.

[24] Milgrom, P., Segal, I., (2002). Envelope theorems for arbitrary choice sets, *Econometrica*, 70, 2, 583-601.

[25] Shavell, S.M., (1980). Damage Measures for Breach of Contract, *Bell Journal of Economics,* 11, 2, 466-490.

[26] Spagnolo, G., (2012). Reputation, Competition and Entry in Procurement, *International Journal of Industrial Organization*, 30, 3, 291-296.

[27] Spulber, D.F., (1990). Auctions and Contract Enforcement, *Journal of Law, Economics and Organizations,* 6, 2, 325-344.

[28] Stubbs, M., (2013). Conservation Reserve Program (CRP): Status and Issues. CRS report for Congress, R42783. Available at http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R42783.pdf (accessed 05 May 2014).

[29] U.S. Department of Agriculture (USDA), (2013). Appendix to form CRP-1. Conservation Reserve Program Contract. Available at http://forms.sc.egov.usda.gov/efcommon/eFileServices/eForms/CRP1_APPENDIX.PDF (accessed 05 May 2014).

[30] White, B., Sadler, R., (2011). Optimal Conservation Investment for a Biodiversity-rich Agricultural Landscape, *Australian Journal of Agricultural and Resource Economics*, 56, 1-21.

[31] Whitten, S., Goddard, R., Knight, A., Reeson, A., and Stevens, D., (2007). Designing and Testing an Outcome Focused Conservation Auction: Evidence from a Field Trial Targeting Ground Nesting Birds, Discussion Paper, CSIRO Sustainable Ecosystems Group. Available at http://bioecon-network.org/pages/10th_2008/13.Whitten.pdf (accessed 05 May 2014).

[32] Wu, J.J., Lin, H., (2010). The effect of the Conservation Reserve Program on land values, *Land Economics*, 86, 1, 1-21.

[33] You, C.Y., Tam, C.S., (2006). Rational Under-Pricing in Bidding Strategy: A Real Options Model, *Construction Management and Economics*, 24, 475-484.

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