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Mitigating Risky Conservation Tenders: Can an Insurance Mechanism Be a Solution?

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The cost of providing environmental goods and services by private landholders is often highly uncertain. However, standard bidding models for conservation tenders often ignore this uncertainty. As a result, they fail to suggest suitable mechanisms to reduce the negative impact of cost uncertainty. We contribute to this knowledge gap by developing an optimal bidding model for a risky and budget-constrained tender in the presence of an *embedded insurance* mechanism, offering income protection. Results from our analysis show that, relative to uninsured landholders, landholders paying an actuarially fair premium tendered lower bids, potentially improving the cost effectiveness of allocating conservation contracts.

Key words: bidding theory, conservation auctions, income protection, own-cost uncertainty, public expenditure

Introduction

Existing research recognizes the critical role of public and private intervention strategies in addressing the environmental concerns induced by human activities. Gunningham (2011) presents several regulatory and compliance strategies from the regulatory literature and suggests the need for regulatory agencies to effectively and efficiently enforce well-designed and targeted intervention strategies to improve desired environmental outcomes. On the other hand, Heyes (2000), highlights three types of compliance instruments: (i) "first wave" or command and control instruments, which enforce compliance and punish noncompliance (Jack, Kousky, and Sims, 2008); (ii) "second wave" or market-based instruments, which encourage a change of behavior through market signals modifying private costs and benefits (Keohane, Revesz, and Stavins, 1998); and (iii) "third wave" instruments, sometimes called "suasion,"'which promote compliance by increasing the availability of information on environmental performance (Tietenberg, 1998). We focus our discussion on resource allocation using market-based instruments, as their application has been strongly advocated for protecting the environment on private land at minimal cost.

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Conservation tenders (CTs) or reverse auctions belong to a category of market-based instruments that, although still infrequent, are gaining popularity globally due to their potential for generating efficiency gains with limited public funding. CTs are incentive-based mechanisms that allocate conservation management contracts to private landholders through a competitive bidding process. The tender process is designed to attract low-cost bids and provide high environmental benefits. The typical parties in a CT are private landholders and a conservation agency. The landholders (often the sellers of environmental goods) submit bids for a given agri-environmental project. The conservation agency (the buyer of environmental goods) ranks and selects the most cost-effective bids using either a predetermined budget (budget-constrained tender) or a predetermined target (target-constrained tender) (Schilizzi and Latacz-Lohmann, 2007; Connor, Ward, and Bryan, 2008). This paper will focus only on budget-constrained tenders, a commonly used policy instrument.

Over the past few decades, conservation agencies in both developed and developing countries have used market-based programs, such as CTs, to engage private landholders in environmental restoration, rehabilitation, and conservation projects (Reichelderfer and Boggess, 1988; Morris and Young, 1997; Stoneham et al., 2003; Wunder, Engel, and Pagiola, 2008; Ajayi, Jack, and Leimona, 2012). In the United States, for instance, the Conservation Reserve Program (CRP) is aimed at reducing soil erosion, improving water quality, and increasing wildlife habitat (Reichelderfer and Boggess, 1988). In the United Kingdom, the Countryside Stewardship Scheme was used to restore damaged landscapes and protect threatened wildlife habitats (Morris and Young, 1997). Finally, in Australia, the Victorian BushTender Program focuses on protecting endangered native vegetation (Stoneham et al., 2003).

The above examples demonstrate the variety of CT programs. Rolfe et al. (2018) classify them into three main groups: (i) rehabilitation of nonarable land; (ii) setting aside farmland for environmental purposes; and (iii) modifying farming techniques to improve the environment. We focus on modified farming techniques, where landholders are required to switch from conventional farming to ecofarming technology. Numerous terms are used to describe ecofarming (see Merrill, 1983; Newman, 1994; Phalan et al., 2011). In this paper, we use the term "ecofarming" in its broadest sense to refer to the adoption of environmentally friendly practices (e.g., limiting the use of pesticides and chemical fertilizers). The analysis may be extended to other types of CT programs by making slight adaptations.

Theory suggests that if CTs are designed and implemented properly, they are efficient in promoting effective use of public funds (Latacz-Lohmann and Van der Hamsvoort, 1997; Müller and Weikard, 2002). The very nature of CTs facilitates competition among landholders, thereby influencing cost revelation. That is, as competition becomes intense, landholders tend to bid closer to their true cost (Cason, Gangadharan, and Duke, 2003; Latacz-Lohmann and Schilizzi, 2005). However, Rolfe et al. (2018) recognize that conservation agencies face numerous challenges during the implementation of CTs. Among these are landholders' strategic bidding behavior, informational asymmetry, and limited participation, all of which undermine the efficiency of CTs despite their potential benefits.

Furthermore, landholders can be exposed to high-cost variability (risk) when delivering environmental goods or services. Therefore, they may demand additional financial incentives as compensation for undertaking "risky" conservation projects. In such situations, conservation agencies may overspend public funds to achieve the desired environmental objectives. If landholders' participation rates are too low, the conservation agencies may not meet their objectives.

Nonetheless, suppose landholders decide to participate in the tender. In that case, they face the challenge of making evaluation mistakes during the bidding process due to factors such as insufficient knowledge of the cost of delivering environmental goods or services (Wichmann et al., 2017); high transaction, opportunity, and learning costs (Cason and Gangadharan, 2004; Rolfe et al., 2018); and uncertainty about the outcome of the undertaken environmental project (Schilizzi and Latacz-Lohmann, 2007). As a result, landholders may encounter difficulties in ascertaining their bid levels. Consequently, they may be caught in the predicament of either bidding too high—thereby losing their chance of winning the tender—or asking for too little and exposing themselves to unwanted risk in the form of a “winner’s curse" (i.e., receiving compensation that is lower than the actual realized cost) (Wichmann et al., 2017).

Current contractual criteria for incentivizing landholders to participate in agri-environmental programs have shortcomings regarding the definition and mitigation of risks. Risk mitigation has not been studied in the context of CTs because the focus has been on bidding behavior and not on participation (Rolfe et al., 2018). By studying risk mitigation, we also shed light on participation, which is an important issue when implementing agri-environmental programs. To ensure sustainable environmental outcomes, it is essential to minimize risk exposure by adopting effective risk management strategies, including targeted agronomic advisory and extension services, education on climate-smart technologies and climate-resilient production systems, and risk transfer through the purchase of appropriately designed and priced insurance products. We focus on this last solution strategy.

Insurance is defined as the transfer of a possible financial loss by a policyholder (insured) to another party (insurer) in exchange for an insurance premium (fee charged by the insurer for taking on the risk). This agreement is defined formally in a policy document that outlines the contract’s terms and conditions. In the context of agriculture, a large volume of published studies describes the role of insurance programs in managing agricultural risks and reducing the financial burden resulting from unforeseen events (Knight and Coble, 1999; Capitanio et al., 2011; Pérez-Blanco, Delacámara, and Gómez, 2016). Existing agricultural insurance products include crop, livestock, and revenue insurance as well as other, nontraditional products such as index-based insurance (Miranda and Vedenov, 2001; Makaudze and Miranda, 2010; Chalise et al., 2017; Reyes et al., 2017). These programs are diversified to accommodate various risks (e.g., low yields, crop failure, wildlife damage, pest and diseases, stock mortality, fire, and weather-related perils such as hail, frost, and drought), thereby protecting landholders from sudden financial loss.

Insurance plays a significant role in managing agricultural risks. It reduces the financial burden resulting from unforeseen events, especially to landholders who are at risk of possible financial ruin in the event of a severe loss. However, the cost of insurance to agricultural producers can be extremely high and consequently hinder insurance adoption rates (Nelson and Loehman, 1987). Therefore, to make insurance programs more attractive to farmers and ensure that they are financially viable for agricultural insurers, there is a need to invest in innovative insurance designs and government intervention that subsidizes, in whole or in part, the insurance premium. The availability of high-quality data can also assist agricultural insurance providers to offer insurance protection at competitive premium rates. Consequently, insurance providers must invest in high-quality data collection to facilitate better risk classification and pricing of agricultural insurance products. All these are essential to reduce the cost of insurance, minimize risk exposure, and ensure the stability of agricultural insurance programs, especially when a catastrophic event occurs (Nelson and Loehman, 1987; Miranda and Glauber, 1997; Barnett, 2000; Mahul and Stutley, 2010).

Since insurance mechanisms have been applied successfully in different agricultural settings (see, e.g., Barnett, 2000), they may also be useful in mitigating some of the risks inherent in CTs. To date, the performance of an insurance mechanism has not been studied in the context of CTs. The present study provides new insights on the performance of CTs in the presence of an *embedded insurance* mechanism. The term “embedded” implies that the insurance mechanism is integrated within the conservation contract and offers income protection to the winning landholders in the event of a financial loss. This is a novel use of the insurance concept in that the conservation agency becomes the main contractor of both the insurance and the conservation contracts.

We have developed an optimal bidding model to answer two main questions: (i) What is the impact of an embedded insurance mechanism on optimal bidding behavior, and (ii) can an embedded insurance mechanism potentially offset the negative impact of own-cost uncertainty? To the best of our knowledge, the impact of an insurance mechanism on optimal bidding behavior has not been explored to date in the conservation auction literature.

Model Setting

This section considers the decision problem for risk-averse landholders under uncertain conditions. While it is essential to allow for uncertainties during the decision-making process, few studies of CTs have incorporated risks, other than the probability of not being selected, in their model formulation. Wichmann et al. (2017) explore the consequences of cost risk in conservation contracts using a utility theoretic framework. They establish that in the presence of cost risk, the risks of losing a tender and of suffering a winner's curse affect the optimal bidding behavior of a risk-averse landholder. We further explore this concept of risk by examining the effect of risk mitigation on landholders' optimal bidding behavior.

To achieve this, we model a budget-constrained tender using a discriminatory pricing rule. In such a tender, the budget is predetermined, and the winning landholders are paid an amount equal to their submitted bids. Let us consider a conservation agency using the above mechanism to implement an agri-environmental program. In this program, landholders are encouraged to switch from conventional farming to a potentially riskier ecofarming technology. Landholders wishing to participate in the program must submit their expression of interest, including their bids and environmental benefits. The conservation agency would then allocate the available contracts until the budget is exhausted.

Risk-Averse Bidders Ecofarming Profit Model Formulation

Ecofarming techniques can provide a range of benefits, such as sustainable yields and improved soil fertility (Chase and Duffy, 1991; Avcı, 2011). However, it is typically believed that these techniques, at least at first, expose landholders to increased profit volatility (Kerselaers et al., 2007; Lauwers et al., 2010). For example, landholders switching from conventional farming to ecofarming technology may have limited experience with the new practice. They would, therefore, form subjective estimates of what their expected profit from ecofarming would be. While the expected profit is based on the landholders' subjective beliefs, the realized *ex post* profit can vary significantly from the expected profit. This is due to various factors such as changes in weather patterns, fluctuations in market prices, or other unforeseen events.

Following Wichmann et al. (2017), we use the expected utility framework to evaluate a risk-averse landholder's certainty equivalent profit under three scenarios. The first scenario estimates the landholder's profit function without embedded insurance; this acts as our baseline case. In the second scenario, we introduce an embedded insurance mechanism with an actuarially fair premium. Here, the insurance premium is equal to the expected loss. In the third scenario, we introduce a premium loading where the insurance premium includes other administrative expenses. The so-called premium loading (also risk or safety loading) is used in the premium calculation principle (see Olivieri and Pitacco, 2011; Straub, 1988, for more details). The same idea is used in production planning where a safety stock is allowed to mitigate the impact of uncertainties on supply chain logistics (Christopher and Lee, 2004; Graves and Willems, 2003).

Baseline: Ecofarming Profit Model without an Embedded Insurance Mechanism

Let $i \in N = \{1,2,\dots,n\}$ denote an eligible landholder (bidder) who wishes to adopt ecofarming technology. Landholder i is assumed to have private knowledge about the expected profit from current farming practice (conventional farming), denoted by $E\pi_{0_i}$. The corresponding certainty equivalent profit is given by the difference between the expected profit and risk premium (i.e., $\mathrm{CE}(\pi_{0_i}) = E\pi_{0_i} - r_{0_i}$, such that $r_{0_i} > 0$). The risk premium, r_{0_i}, represents the maximum amount a risk-averse bidder is willing to pay for protection against a potential loss and is conditional on an individual landholder's subjective choice of a probability distribution. Landholders are also assumed to have optimized their conventional farming enterprise in such a way that it incorporates their perceived risk. This is less restrictive than it appears, given that we are mainly interested in the additional uncertainty brought about by adopting ecofarming technology.

To simplify the analysis, consider an ecofarming technology with two possible income states: a high-income state with profit π_i and a low-income state with profit $\pi_i - \omega_i$, where $\omega_i < \pi_i$ represents the magnitude of income loss from ecofarming. Furthermore, ω_i is assumed to follow a uniform distribution on the support $(0,\pi_i)$.

Suppose landholder i's subjective probability of being in the low-income state is q_i and the probability of being in the high-income state is $(1 - q_i)$. The probability of income loss expresses an individual landholder's belief about the likelihood of the occurrence of a loss event ω_i; where ω_i represents a negative deviation from the benchmark profit, π_i. The expected utility from adopting ecofarming technology with two outcome states is given by

$$\text{(1)} \qquad \mathrm{EU}(\pi_i) = q_i \mathrm{U}(\pi_i - \omega_i) + (1 - q_i)\mathrm{U}(\pi_i),$$

where $\mathrm{U}(\cdot)$ is assumed to be an increasing and concave von Neumann–Morgenstern utility function. In order to obtain the certainty equivalent profit that maximizes equation (1), let $\mathrm{U}(\cdot)$ be characterized by a constant relative risk-aversion (CRRA) utility function,[1] taking the form

$$\text{(2)} \qquad \mathrm{U}(x) = \begin{cases} \frac{x^{1-\rho_i}}{1-\rho_i} & \text{if } \rho_i \neq 1, \\ \ln(x) & \text{if } \rho_i = 1, \end{cases}$$

where parameter ρ_i denotes landholder i's degree of risk aversion. By substituting equation (2) in equation (1) we get

$$\text{(3)} \qquad \mathrm{EU}(\pi_i) = \begin{cases} \frac{q_i(\pi_i-\omega_i)^{1-\rho_i}+(1-q_i)\pi_i^{1-\rho_i}}{1-\rho_i} & \text{if } \rho_i \neq 1, \\ q_i \ln(\pi - \omega_i) + (1 - q_i)\ln(\pi_i) & \text{if } \rho_i = 1, \end{cases}$$

and the certainty equivalent profit, denoted by $\mathrm{CE}(\pi_i)$, is derived using the formulation $\mathrm{U}(\mathrm{CE}(\cdot)) = \mathrm{EU}(\cdot)$ (see, e.g., Mas-Colell, Whinston, and Green, 1995). If we substitute equations (2) and (3) in $\mathrm{U}(\mathrm{CE}(\cdot)) = \mathrm{EU}(\cdot)$ we get

$$\text{(4a)} \qquad \mathrm{CE}(\pi_i) = \begin{cases} [(1 - \rho_i)\mathrm{EU}(\pi_i)]^{\frac{1}{1-\rho_i}} & \text{if } \rho_i \neq 1, \\ e^{\mathrm{EU}(\pi_i)} & \text{if } \rho_i = 1. \end{cases}$$

$$\text{(4b)} \qquad = \begin{cases} [q_i(\pi_i - \omega_i)^{1-\rho_i} + (1 - q_i)\pi_i^{1-\rho_i}]^{\frac{1}{1-\rho_i}} & \text{if } \rho_i \neq 1, \\ (\pi - \omega)^{q_i}\pi^{1-q_i} & \text{if } \rho_i = 1. \end{cases}$$

Next, we evaluate landholder i's ecofarming profit model in the presence of an embedded insurance mechanism.

Ecofarming Profit Model in the Presence of an Embedded Insurance Mechanism

Let us now consider the scenario in which landholder i elects to insure themself against the loss of ω_i. If the insurer determines the insurance premium following a pre-agreed-upon maximum loss (i.e., ω_i in our case), the landholder's expected utility from adopting ecofarming technology in the presence of an insurance mechanism can be written as

[1] We employed the CRRA utility function due to its homothetic preferences; it is a commonly used utility function in the economics literature (Battermann, Broll, and Wahl, 1997; Levy and Levy, 2021). Although the focus of this article is on decisions of risk-averse landholders with CRRA utility function, the model can be extended to other risk types and utility functions. This does not affect the generality of our analysis.

(5) $$\mathrm{EU}(\pi_{ins_i}) = \mathrm{U}(\pi_i - P_{ins_i}),$$

which denotes the landholder's utility in both low- and high-income states; $P_{ins_i} = q_i \omega_i$ represents the actuarially fair premium (AFP). In the insurance literature, AFP is synonymous with pure or gross premium (i.e., the insurance premium equals expected loss). This premium is without any expenses. The certainty equivalent profit that maximizes equation (5) is given by

(6) $$\mathrm{CE}(\pi_{ins_i}) = \pi_i - P_{ins_i},$$

which differs from equation (4b) in that the net income in equation (6) is the same in both low- and high-income states. This is because the landholder trades off the risk of losing ω_i in the low-income state with an insurance premium equal to the expected loss. Additionally, $\mathrm{CE}(\pi_{ins_i})$ is independent of the risk-aversion parameter ρ_i.

When a loss event occurs (i.e., a low-income state), the landholder receives full compensation up to a pre-agreed-upon maximum loss. By contrast, when there is no loss (i.e., a high-income state), the landholder's net income reduces by an amount that is equal to the AFP. A risk-averse landholder derives more utility from a guaranteed income in both income states rather than a high income when there is no loss and a low income when a loss event occurs. Therefore, it would be optimal for that landholder to purchase full insurance coverage with an AFP (see Borch, 1983).

Next, we modify equations (5) and (6) by incorporating a premium loading. Suppose the insurer applies a premium loading, $\alpha > 0$, on P_{ins_i}, such that equation (5) becomes

(7) $$\mathrm{EU}(\pi^L_{ins_i}) = \mathrm{U}[\pi_i - (1+\alpha)P_{ins_i}],$$

where αP_{ins_i} denotes the proportion of insurance premium that covers administrative expenses. Note that a landholder's insurance premium is greater than the AFP with the introduction of the premium loading. The certainty equivalent profit that maximizes equation (7) is

(8) $$\mathrm{CE}(\pi^L_{ins_i}) = \pi_i - (1+\alpha)P_{ins_i}.$$

Again, we see that equation (8) is independent of the risk-aversion parameter. Also, $\mathrm{CE}(\pi_{ins_i}) > \mathrm{CE}(\pi^L_{ins_i})$ whenever $\alpha > 0$, implying that the certainty equivalent profit for landholders without premium loading is always greater than that of landholders with premium loading. The opportunity cost of switching from conventional farming to ecofarming technology can be written as

(9) $$c_i = \mathrm{CE}(\pi_{0_i}) - \mathrm{CE}(\cdot),$$

where $\mathrm{CE}(\cdot)$ is given by equations (4b), (6), and (8). In the next section, we provide an outline of a risk-averse landholder's optimal bidding model in both uninsured and insured scenarios.

Optimal Bidding Model Formulation for a Risk-Averse Bidder

To begin the analysis, suppose that a risk-averse landholder with opportunity cost c_i and fixed transaction cost A_i submits bid b_i. In our model formulation, we assume that the landholder's bidding decision is influenced by two types of costs: (i) the opportunity cost of participating in the tender and (ii) the transaction costs incurred during the bid preparation. This decision is made *ex ante*, before the occurrence of the events that will determine their actual costs and profits. If landholder i believes that their bid, an element of $\Omega = \{b_1, b_2, \ldots, b_n\}$, is in position $1 \le r \le n$, the probability that landholder i wins the tender is given by the success function $1 - F(b_i)$ (Latacz-Lohmann and Van der Hamsvoort, 1997):

$$1 - F(b_i) = \int_{b_i}^{\bar{\beta}} f(b_i) db_i > 0, \tag{10}$$

where $f(b_i)$ denotes the probability density function and $F(b_i)$ is the corresponding cumulative distribution function, representing the rejection probability. Equation (10) represents the probability that landholder i submits a bid that is lower than the maximum acceptable bid cap, $\bar{\beta}$, which is unknown to the landholders. We assume that equation (10) is strictly decreasing in $b_i : \underline{\beta_i} \leq b_i \leq \bar{\beta}$, where $\underline{\beta_i}$ denotes the minimum bid cap while $\bar{\beta}$ is the maximum bid above which the landholder is sure of not getting selected in the auction. Additionally, we assume that $\bar{\beta}$ is unknown to landholders.

Suppose landholder i applies bidding strategy $b_i = b_i(c_i)$, where the function $b_i(\cdot)$ is assumed to be an increasing function of the opportunity cost, c_i. The expected net income that maximizes landholder i's utility from adopting ecofarming is given by

$$[1 - F(b_i)][b_i - c_i] - \mathrm{A}_i. \tag{11}$$

Expression (11) has three components. The first component is landholder i's probability of winning the tender, which is given by the first product term. The second component is landholder i's rent (i.e., the difference between the bid, b_i, and the opportunity cost, c_i), which is given by the second product term. The third component, A_i, is a fixed transaction cost.

Expression (11) articulates a risk-averse landholder's trade-off between a high probability of winning the tender and a high probability of maximizing the rent. Formulating a lower bid increases the selection probability but reduces the chance of earning a higher rent and therefore increases the risk of suffering a winner's curse. At the same time, submitting a higher bid reduces the selection probability but increases the rent and hence lowers the risk of a possible winner's curse. The profit maximization problem for a risk-averse landholder is therefore

$$\begin{cases} \underset{b}{\text{maximize}} & [1 - F(b_i)][b_i + \mathrm{CE}(\cdot)] + F(b_i)\mathrm{CE}(\pi_{0_i}) - \mathrm{A}_i, \\ \text{subject to:} & [1 - F(b_i)][b_i - c_i] \geq \mathrm{A}_i, \\ & b_i \geq \underline{\beta_i}. \end{cases} \tag{12}$$

The constraint $[1 - F(b_i)][b_i - c_i]$ represents the participation constraint for a risk-averse landholder. It ensures that the expected rent is enough to cover the fixed transaction cost. This allows us to focus on the landholder's participation behavior in the presence of own-cost uncertainty. The constraint $b_i \geq \underline{\beta_i}$ restricts the lower bound of b_i to the minimum bid cap, $\underline{\beta_i}$. Submitting a bid below $\underline{\beta_i}$ does not improve the selection probability; moreover, it reduces the chance of earning a higher expected rent. As Latacz-Lohmann and Van der Hamsvoort (1997) note, it makes no economic sense for landholders to submit bids below the minimum bid cap. Solving the maximization problem with respect to b_i yields the first-order condition

$$b_i^* = c_i + \frac{1 - F(b_i^*)}{f(b_i^*)}, \tag{13a}$$

$$= \mathrm{CE}(\pi_{0_i}) - \mathrm{CE}(\pi_i) + \frac{1 - F(b_i^*)}{f(b_i^*)}, \tag{13b}$$

where b_i^* denotes the optimal bidding function for a risk-averse landholder. Landholder i maximizes their expected net income from ecofarming by including an opportunity cost, c_i, and an additional mark-up, $\frac{1-F(b_i^*)}{f(b_i^*)}$, referred to as a participation premium. Equation (13b) implicitly defines landholder i's optimal bid, b_i^*, which is a function of the own-cost uncertainty variables (i.e., the subjective probability, q_i, and magnitude, ω_i, of income loss). The next section explores the impact of introducing an insurance mechanism on optimal bidding behavior.

Optimal Bidding Model Formulation for a Risk-Averse Bidder in the Presence of an Insurance Mechanism

We now consider an embedded insurance mechanism and its impact on a risk-averse landholder's bidding behavior. The term "embedded" implies that the insurance policy is integrated within the conservation contract and offers income protection when there is a loss event. The timing of events is critical during the tender process. In the bid formulation stage, a landholder estimates their expected profit from ecofarming. Next, the insurer determines the insurance premium following a pre-agreed-upon maximum loss. Finally, landholders formulate their equilibrium bidding strategy using the expected profit and insurance premium information. The insurer will compensate the winning landholders up to the pre-agreed-upon maximum loss when a loss event occurs.

Since the risk of losing an income, ω_i, has been mitigated by the embedded insurance, the landholder only faces the risk of losing the tender if the submitted bid is higher than the unknown maximum acceptable bid. Therefore, a landholder would find it profitable to purchase insurance if it yields a higher expected utility of net income. By definition, bidding under lower opportunity cost will result in a lower optimal bid and, hence, a higher probability of winning the tender. Moreover, an insurance mechanism would benefit the landholder because it reduces the downside risk and ensures income stability for the landholder. The implicit solution to the first-order condition is given by

(14a)
$$b_{ins_i}^* = c_i + \frac{1 - F(b_{ins_i}^*)}{f(b_{ins_i}^*)},$$

(14b)
$$= \text{CE}(\pi_{0_i}) - \text{CE}(\cdot) + \frac{1 - F(b_{ins_i}^*)}{f(b_{ins_i}^*)},$$

where $b_{ins_i}^*$ denotes the optimal bidding function for a risk-averse landholder with embedded insurance and $\text{CE}(\cdot)$ is given by equations (6) and (8).

After setting up the optimal bid model, we explore how changes in the main components of own-cost uncertainty (i.e., probability, q_i, and magnitude, ω_i, of income loss; premium loading, α; and the risk-aversion parameter, ρ_i) influence the optimal bid.

Impact of Own-Cost Uncertainty Variables on the Optimal Bid

To test the sensitivity of the optimal bid to own-cost uncertainty variables, we apply the implicit function theorem to the optimal bid function. Table 1 summarizes the impact of q_i and ω_i on risk-averse landholders' optimal bidding behavior.

We note that the partial derivative of $b_{(\cdot)}^*$ with respect to the probability of income loss (i.e., $\partial b_{(\cdot)}^* / \partial q_i$) is increasing in q_i for all values of $\omega_i > 0$. Similarly, an increase in the magnitude of income loss, ω_i, lowers the expected profit from ecofarming, thereby increasing the opportunity cost.

Proof. Increasing probability and magnitude of income loss.

Table 1. Sensitivity Analysis of the Optimal Bid

Scenarios	Rate of Change in Optimal Bid for Risk-Averse Landholders
	$\frac{\partial(b_i^*)}{\partial q_i} = \frac{\left(\pi_i^{\rho_i}(\pi_i-\omega_i)-\pi_i(\pi_i-\omega_i)^{\rho_i}\right)f(b_i)\left(q_i(\pi_i-\omega_i)^{1-\rho_i}-\pi_i^{1-\rho_i}(q_i-1)\right)^{\frac{1}{1-\rho_i}}}{(\rho_i-1)\left(\pi_i^{\rho_i}q_i(\pi_i-\omega_i)-\pi_i(q_i-1)(\pi_i-\omega_i)^{\rho_i}\right)} > 0$
Uninsured	$\frac{\partial(b_i^*)}{\partial \omega_i} = q_i(\pi_i-\omega_i)^{-\rho_i} f(b_i)\left(q_i(\pi_i-\omega_i)^{1-\rho_i}-\pi_i^{1-\rho_i}(q_i-1)\right)^{\frac{1}{1-\rho_i}-1} > 0$
	$\frac{\partial(b_i^*)}{\partial \rho_i} = -\frac{\ln\left(q_i(\pi_i-\omega_i)^{1-\rho_i}-\pi_i^{1-\rho_i}(q_i-1)\right)+\frac{(1-\rho_i)\left(\pi_i^{1-\rho_i}(q_i-1)\log(\pi_i)-q_i(\pi_i-\omega_i)^{1-\rho_i}\log(\pi_i-\omega_i)\right)}{q_i(\pi_i-\omega_i)^{1-\rho_i}-\pi_i^{1-\rho_i}(q_i-1)}}{(\rho_i-1)^2}$
Insured with actuarially fair premium	$\frac{\partial(b_{ins_i}^*)}{\partial q_i} = -\frac{\frac{\partial P_{ins_i}}{\partial q_i} f(b_{ins_i}^*)}{-2f\left(b_i^*\right)-f'\left(b_i^*\right)[b_i^*-c_i(\cdot)]} > 0$
	$\frac{\partial(b_{ins_i}^*)}{\partial \omega_i} = -\frac{\frac{\partial P_{ins_i}}{\partial \omega_i} f(b_{ins_i}^*)}{-2f\left(b_{ins_i}^*\right)-f'\left(b_i^*\right)[b_{ins_i}^*-c_i(\cdot)]} > 0$
	$\frac{\partial(b_{ins_i}^*)}{\partial q_i} = -\frac{\frac{\partial \alpha P_{ins_i}}{\partial q_i} f(b_{ins_i}^*)}{-2f\left(b_{ins_i}^*\right)-f'\left(b_{ins_i}^*\right)[b_{ins_i}^*-c_i(\cdot)]} > 0$
Insured with premium loading	$\frac{\partial(b_{ins_i}^*)}{\partial \omega_i} = -\frac{\frac{\partial \alpha P_{ins_i}}{\partial \omega_i} f(b_{ins_i}^*)}{-2f\left(b_{ins_i}^*\right)-f'\left(b_{ins_i}^*\right)[b_{ins_i}^*-c_i(\cdot)]} > 0$
	$\frac{\partial(b_{ins_i}^*)}{\partial \alpha} = -\frac{\frac{\partial P_{ins_i}}{\partial \alpha} f(b_{ins_i}^*)}{-2f\left(b_{ins_i}^*\right)-f'\left(b_{ins_i}^*\right)[b_{ins_i}^*-c_i(\cdot)]} > 0$

Notes: Optimal bid is with respect to landholder's probability of income loss, q_i; magnitude of income loss, ω_i; risk-aversion parameter, $\rho_i : 0 < \rho_i < 1 \mid\mid \rho_i > 1$); and premium loading, α.

Let us consider the optimal bid function of a risk-averse landholder with embedded insurance. Suppose the magnitude of income loss increases by a value $\epsilon_i > 0$ such that $\omega_i = \omega_i + \epsilon_i$; equation (14b) simplifies to

$$b_{ins_i}^* = \text{CE}(\pi_{0_i}) - [\pi_i - q_i(\omega_i + \epsilon_i)] + \frac{1 - F(b_{ins_i}^*)}{f(b_{ins_i}^*)}, \tag{15a}$$

$$= \text{CE}(\pi_{0_i})[\pi_i - P_{ins_i}] + q_i\epsilon_i + \frac{1 - F(b_{ins_i}^*)}{f(b_{ins_i}^*)}, \tag{15b}$$

$$= \text{CE}(\pi_{0_i}) - \text{CE}(\pi_{ins_i}) + q_i\epsilon_i + \frac{1 - F(b_{ins_i}^*)}{f(b_{ins_i}^*)}, \tag{15c}$$

The implication is that, as the magnitude and probability of loss rise, the opportunity cost of participation increases, resulting in higher optimal bids. ■

Changes in Optimal Bid between Uninsured and Insured Scenarios

We now examine the difference between the optimal bids in equations (13b) and (14b). Suppose a risk-averse landholder elects to purchase income protection insurance. Is the reduction in the optimal bid greater than the value of the insurance premium? This reduction, defined as $\Delta b_i^* = b_i^* - b_{ins_i}^*$, is given by

(16a) $$\Delta b_i^* = b_i^* - b_{ins_i}^*,$$

(16b) $$= \text{CE}(\cdot) - \text{CE}(\pi_i) + \underbrace{\left[\frac{1 - F(b_i^*)}{f(b_i^*)} - \frac{1 - F(b_{ins_i}^*)}{f(b_{ins_i}^*)}\right]}_{\text{D}},$$

where $\text{CE}(\cdot) - \text{CE}(\pi_i)$ represents the change in the certainty equivalent profit between the insured and uninsured scenarios and the term D represents the change in the participation premium. The inverse of the participation premium is the hazard rate function $(f(b_{(\cdot)}^*)/1 - F(b_{(\cdot)}^*))$, which represents the instantaneous rejection rate at the optimal bid (Wichmann et al., 2017). In order to gain insight into the solution in equation (16b), we consider both constant and increasing hazard rate functions.

PROPOSITION 1. *Constant Hazard Function.*

Suppose the hazard rate function is constant (and $\neq 0$*), then the inverse of the hazard rate function (i.e., the participation premium) in both insured and uninsured scenarios would be equal, implying that change in the optimal bid function* $\Delta b_i^* > 0$*, so that insurance favors more aggressive bidding behavior.*

Proof. Insured with actuarially fair premium.

Suppose $P_{ins} = q_i \omega_i$, then equation (16a) simplifies to

(17a) $$\Delta b_i^* = b_i^* - b_{ins_i}^*,$$

(17b) $$= \text{CE}(\pi_{ins_i}) - \text{CE}(\pi_i),$$

(17c) $$= r_i > 0,$$

where r_i represents the risk premium for a risk-averse landholder; this is given by the difference between the expected profit from ecofarming and the certainty equivalent profit defined in equation (4b). The risk premium is conditional on the landholder's degree of risk aversion and the subjective probability of income loss. This implies that the magnitude of the risk premium will depend on the landholder's utility function and the size of risky alternatives. ■

In the presence of premium loading, equation (17b) can be rewritten as

(18a) $$\Delta b_i^* = \text{CE}(\pi_{ins_i}^L) - \text{CE}(\pi_i),$$

(18b) $$= r_i - \alpha P_{ins}.$$

Equation (18b) suggests that, for a given value of the premium loading factor α, the reduction in the optimal bid is greater than 0 as $r_i > \alpha P_{ins}$. In the case where $r_i < \alpha P_{ins}$, the value $\Delta b_i^* < 0$, suggesting that $b_i^* < b_{ins_i}^*$. This is because the certainty equivalent is greater in the uninsured scenario than in the insured scenario. Therefore, landholders would find it beneficial to bid according to equation (13b). Next, we consider an increasing hazard rate function.

PROPOSITION 2. *Increasing Hazard Function.*

Let us suppose that the hazard rate function is increasing; then, the inverse of the hazard rate function (i.e., the participation premium) is decreasing.

Proof. Insured with actuarially fair premium.

Suppose $P_{ins} = q_i\omega_i$, then equation (16a) can be rewritten as

$$\Delta b_i^* = b_i^* - b_{ins_i}^* = r_i + \underbrace{\left[\frac{1-F(b_i^*)}{f(b_i^*)} - \frac{1-F(b_{ins_i}^*)}{f(b_{ins_i}^*)}\right]}_{\text{D}}. \tag{19}$$

To show that the bidding behavior is more aggressive, assume on the contrary that equilibrium bidding behavior is such that $b_{ins_i}^* > b_i^*$. Then, the lefthand side of equation (19) is strictly negative. However, for equality (19) to hold, the term D should be strictly negative, given that $r_i > 0$. For this to be true, the participation premium should be strictly increasing; this contradicts our primary assumption that the participation premium is decreasing. Hence, we conclude that, in this case, we always have $b_{ins_i}^* < b_i^*$. ■

In the presence of premium loading equation (19) becomes

$$\Delta b_i^* = b_i^* - b_{ins_i}^* = [r_i - \alpha P_{ins_i}] + \underbrace{\left[\frac{1-F(b_i^*)}{f(b_i^*)} - \frac{1-F(b_{ins_i}^*)}{f(b_{ins_i}^*)}\right]}_{\text{D}}. \tag{20}$$

The term D is strictly positive if $b_i^* > b_{ins_i}^*$. However, in the case where the value $[r_i - \alpha P_{ins_i}] < 0$, bidding can be less aggressive if $|r_i - \alpha P_{ins_i}| > \text{D}$.

Proof. Insured with premium loading.

To show that bidding behavior is less aggressive, assume on the contrary that equilibrium bidding behavior is such that $b_{ins_i}^* < b_i^*$. Then, the lefthand side of equation (20) is strictly positive. However, for equality (19) to hold, the term $|r_i - \alpha P_{ins_i}| > \text{D}$, given that D is strictly positive by proposition (2). In the situation where the insurance premium loading is higher than the risk premium and the absolute value is greater than D, the righthand side of (20) would be negative. ■

In order to gain insight into the impact of risk aversion on the change in optimal bidding behavior, let us suppose that the probability density functions, $f(b_i^*)$ and $f(b_{ins_i}^*)$, are uniformly distributed on the support $[\underline{\beta}_i, \bar{\beta}_i]$. Then equation (20) simplifies to

$$\Delta b_i^* = \frac{1}{2}\left(-(\alpha+1)q_i\omega_i - \left(q_i(\pi_i-\omega_i)^{1-\rho_i} - \pi_i^{1-\rho_i}(q_i-1)\right)^{\frac{1}{1-\rho_i}} + \pi_i\right). \tag{21}$$

By differentiating Δb_i^* with respect to the landholder's degree of risk aversion, ρ_i, we obtain

$$\frac{\partial(\Delta b_i^*)}{\partial\rho_i} = -\frac{1}{2}\left(\frac{ln\left(q_i(\pi_i-\omega_i)^{1-\rho_i} - \pi_i^{1-\rho_i}(q_i-1)\right)}{(1-\rho_i)^2}\right.$$
$$\left. + \frac{\pi_i^{1-\rho_i}(q_i-1)\,ln(\pi_i) - q_i(\pi_i-\omega_i)^{1-\rho_i}ln(\pi_i-\omega_i)}{(1-\rho_i)\left(q_i(\pi_i-\omega_i)^{1-\rho_i} - \pi_i^{1-\rho_i}(q_i-1)\right)}\right) \tag{22}$$
$$\left(q_i(\pi_i-\omega_i)^{1-\rho_i} - \pi_i^{1-\rho_i}(q_i-1)\right)^{\frac{1}{1-\rho_i}}.$$

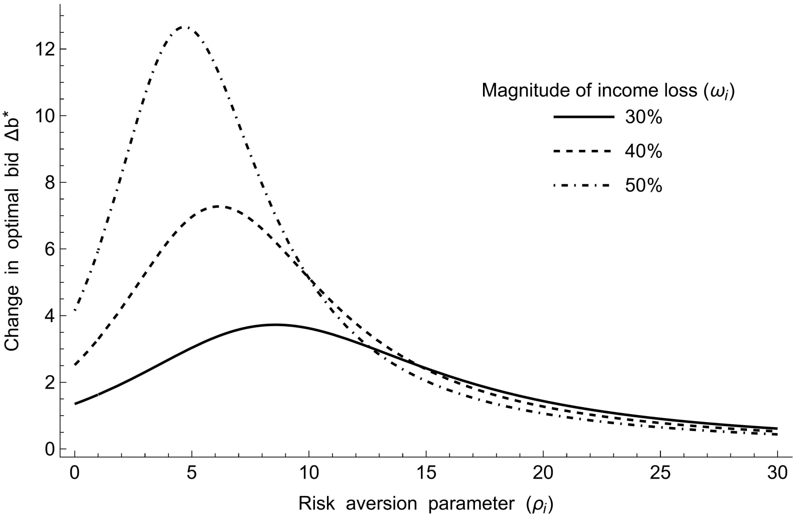

Figure 1. Association between Landholders' Risk-Aversion Parameter and the Change in Optimal Bid between Uninsured and Insured Scenarios

Notes: Analysis was performed at three magnitudes of income loss. The graph assumes a constant relative risk-aversion function taking the form $U(x) = \frac{x^{1-\rho_i}}{1-\rho_i}$, where x denotes the profit variable. The parameter values for the baseline profit and probability of income loss were \$590 and 10%, respectively. The analysis was implemented using Mathematica v12.2.

Equation (22) suggests that the range of the reduction in the optimal bid depends on the assumption about the landholder's own-cost variables. Since equation (22) is an implicit function of the optimal bid, the next section uses numerical simulations to give a better understanding of the model's sensitivity to the risk-aversion parameter, ρ_i.

Numerical Simulations

Numerical simulations enable deeper analysis of the theoretical model by introducing quantitative specifications, giving a better understanding of the model's sensitivity. For the purpose of sensitivity analysis, the parameter values for landholders' magnitude of income loss, ω_i, were generated using a uniform distribution over the range $\omega_i \in (0,\pi_i)$. We varied the probability of income loss, q_i, over the range of 0%–40%. Although higher values of q_i can be used, our analysis has proceeded with the assumption that landholders have an adequate understanding of the risk they may be exposed to when adopting ecofarming technology. Overall, higher values of q_i lead to increased optimal bid values. The analysis was then implemented using Mathematica v12.2. Figure 1 highlights the impact of the risk-aversion parameter on Δb_i^* at three different magnitudes of income loss.

From Figure 1, it can be seen that the relationship between Δb_i^* (i.e., the difference in optimal bid between uninsured and insured scenarios) and the risk-aversion parameter, ρ_i, varies with the probability and magnitude of income loss. For instance, at low levels of ρ_i, the change in the optimal bid between uninsured and insured scenarios increases as ρ_i rises to a maximum point but then starts to fall. This pattern is consistent with that reported by Wichmann et al. (2017), who find that below the maximum risk-aversion level, optimal bid rises in response to cost uncertainty (i.e., risk of winner's curse). However, at higher risk-aversion levels, the incentive to win the tender forces landholders to submit lower bids, resulting in lower bidding levels in both uninsured and insured scenarios.

We also see that with the increasing magnitude of income loss, optimal bid values are higher at lower risk-aversion levels but fall with higher risk aversion, implying that the benefits of having embedded insurance increase with a higher magnitude of income loss. These results suggest that there is value in minimizing the magnitude of income loss. The greater the share of bidders for which the change in the optimal bid is greater than 0 (i.e., $\Delta b_i^* > 0$), the higher the cost effectiveness of an auction with an embedded insurance mechanism.

Discussion

One of the theoretical advantages of competitive bidding is its ability to induce cost revelation. However, this advantage is likely to erode in the presence of own-cost uncertainties. In this paper, we have explored the impact of own-cost uncertainty and the influence of an insurance mechanism on optimal bidding behavior using two main descriptors: the probability, q_i, and magnitude, ω_i, of income loss. Based on the optimal bidding model for a risk-averse landholder and considering q_i and ω_i, we have observed that the optimal bid rises as both values of q_i and ω_i rise. Given higher values of q_i and ω_i, implying a higher expected loss, the expected opportunity cost also rises, leading to a higher optimal bid. This finding is consistent with the experimental study by Wichmann et al. (2017), who found that participants tendered higher bids in the presence of cost risk.

To reduce the negative impact of unexpected losses and promote the achievement of environmental goals, the conservation agencies can integrate suitable risk management tools into CT contracts. We examined the impact of introducing embedded insurance on the optimal bidding model for a risk-averse landholder. With the introduction of an insurance mechanism that offers full and secure compensation when a loss event occurs, our model shows that a risk-averse landholder will tender a lower bid when the premium is equal to the expected loss. This is because the resulting net income is higher with insurance than in the absence of insurance.

Introducing insurance may also strengthen the cost revelation property of the tender, as landholders are more likely to reveal their correct cost estimates through their bids. If the cost is underestimated, a given landholder will receive a lower compensation in the event of a loss. Conversely, if the cost is overestimated, the landholder would attract a high premium and reduce the chance of winning the tender due to a higher bid. Insurance is beneficial to landholders because it eliminates potential downside risks and ensures income stability. Therefore, it would be attractive to landholders who may be willing to participate in environmental programs but are often reluctant because of a possible financial loss they believe they cannot afford. An insurance mechanism will depend on what is being insured, the presence of existing technologies, and the socioeconomic context of insurance. For example, different cultures or economies have different forms of insurance programs. These elements need to be considered when designing an appropriate insurance mechanism in the context of conservation tenders.

This study has addressed the question of whether an insurance mechanism can be a solution for mitigating cost risks in CTs. We have demonstrated, subject to specific but reasonable assumptions, that when landholders operate in an uncertain profit environment, insurance can make the tender more attractive by reducing the corresponding uncertainty and leading to aggressive bidding. The implication is that the regulator can promote participation rates and increase the cost effectiveness of conservation programs by incorporating a risk mitigation strategy, such as an insurance scheme, when designing conservation contracts.

Conclusion

In the past, conservation agencies have viewed CTs as one-dimensional; they have assumed that landholders had complete knowledge of the costs involved in delivering environmental goods or services. Therefore, the conservation agency had to address a design that focused on landholders' bid amounts. More recently, in an international review of participation in CTs, Rolfe et al. (2018) emphasized the importance of landholders' participation, thereby providing us with a two-dimensional view of CTs. This view incorporates bid amounts and participation rates. However, as we have shown, there is still a third dimension of CTs to be considered: risk mitigation. Incorporating the three dimensions of bid amounts, participation rates, and risk mitigation would yield "smart design" CTs. This study suggests that sustainable environmental outcomes can be achieved if a conservation agency creates and effectively implements these smart design CTs.

Our model can be extended in several ways to test the robustness of our findings. First, to simplify our model, we examined an ecofarming program where the expected income from ecofarming had two discrete, low- and high-income states; a general case would involve continuous states. Second, given that this was the first study to investigate the impact of insurance on optimal bidding behavior in the context of a conservation tender, we only considered the case in which landholders had prior information about receiving full and secure insurance before submitting their bid. Additionally, we did not analyze the interaction between the premium loading and risk aversion. Relaxing these assumptions would generate more understanding of the effectiveness of using an insurance mechanism in a less perfect environment. Third, we assumed that landholders make one-shot, irreversible decisions and incur all costs upfront. A possible extension would be to analyze compliance dynamics and how they might affect bidding and participation incentives.

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