When should biodiversity tenders contract on outcomes?

Russell Gorddard[1] , Stuart Whitten[1], Andrew Reeson[1].

[1] CSIRO Sustainable Ecosystems

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Contributing author contact details: Russell Gorddard, CSIRO Sustainable Ecosystems, GPO Box 284, Canberra ACT 2601, Australia. Russell.Gorddard@csiro.au +61 2 6242 1727.

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Abstract

Abstract: Making conservation program payments conditional on outcomes offers potential efficiency and innovation improvements over input based contracts. This paper explores the trade-offs involved in choosing the payment criteria for biodiversity tenders. A model where the budget for a conservation tender can be allocated to input, outcome or mixed payments is used to explore the impacts of hidden actions, adverse selection, and landholder risk aversion on the optimal policy design. We discuss the implications of these results for the design of the 'Nest Egg' tender. This tender is targeting habitat and breeding of ground-nesting birds in the New South Wales Murray Catchment.

Key Words: OUTCOME CONTRACTS, RISK AVERSION, BIODIVERSITY TENDERS, CONTRACT DESIGN, NEST EGG

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1 Introduction

Auctions have shown great promise in improving the overall efficiency of environmental programs, reducing costs to government of achieving specific outcomes, reducing risk to landholders, and fitting in with existing government programs and processes (Stoneham et al., 2003; Grafton, 2005).

However almost all biodiversity incentive programs in Australia, including auctions, are based on either payments for inputs or on modelled outcomes of proposed input changes. Paying for desired biodiversity outcomes rather than specific production methods has several potential benefits. If the desired biodiversity outcome requires active, ongoing management that is difficult to monitor, then outcome payments may motivate these hidden or non-verifiable actions. In addition, if landholders have private information about the potential value for biodiversity of their management actions, outcome based payments may provide an incentive to reveal this information and permit a more efficient allocation of resources. By permitting flexibility in how outcomes are achieved, an outcome based payment system may also reduce costs to the landholders and governments. Finally by providing flexibility and rewarding efficiency, outcome payments may also encourage greater innovation.

Biodiversity tenders with outcome payments could therefore be a valuable policy instrument for managing biodiversity. To this end, an outcome based tender with the aim of increasing ground nesting birds habitat and populations is being trialled in the Murray catchment management area of New South Wales. The project, called Nest Egg, is focusing on three ground nesting bird species: Brolga, Bush stone-curlew and Plains wanderer. These species are in decline in the sheep-wheat belt of Australia in response to habitat modification and predator introduction. Conservation of these species involves some known and verifiable actions, such as wetland restoration and rehabilitation, and stock management to deliver the required habitat quality. There are also significant hidden actions, such as predator control and the precise timing and level of grazing. Due, in part to scientific uncertainty about habitat requirements, there is also unknown potential for innovation by landholders to further improve conservation outcomes of these species. Appropriate management actions may be detailed, ongoing and difficult to monitor generating a significant hidden action problem. Given limited data on bird populations, distributions and habitat requirements, it is also likely that landholders, by virtue of having observed the history of birds on their land, will have private knowledge about the likely habitat value.[1] Hidden information as well as hidden action issues therefore need to be considered in the policy design. The Nest Egg trial therefore provides an opportunity to test the effectiveness of outcome based incentives.

While there are clear benefits to incorporating outcome payments into biodiversity tenders, there are also a range of potential problems and costs that need to be considered in the design. First monitoring costs may affect the optimal policy design. Large outcome monitoring costs could make an outcome payment scheme inefficient. However we need to weigh this against the reduced costs of monitoring input based scheme as well as the other outcome benefits. Outcome based schemes also necessarily transfer the risk of achieving the outcomes onto the landholder. The

[1] The call for expressions of interest in the Nest Egg tender revealed bird populations that were previously unknown to the Catchment Management Authority.

landholder's perceived risk of achieving an outcome based payment may be high as there are compounded uncertainties associated with novel production, monitoring and tender systems. Risk aversion by landholders could therefore influence the optimal policy design. That is the risk premium required for outcome based contracts may favour input based payments.

Monitoring of rare species, especially those that rely on their ability to hide from predators for protection, can be imperfect as well as costly. For risk neutral landholders, imperfections in monitoring should not affect the ability to design an incentive compatible outcome payment (Laffont and Martimort, 2002). Essentially the nominal outcome price can be increased in order to produced the same expected reward and induce the optimal level of effort. However this increase in uncertainty can be important if landholders are risk averse.

Biodiversity outcomes are also difficult to define precisely. Nest Egg focuses on bird presence and breeding, as these are ends in themselves but also because they provide a direct indicator of the functionality of the ecosystem with respect to other species that occupy similar habitat niches, and a proxy for general ecosystem health. Since it is only feasible to contract for a subset of the desired outcomes, there is a risk of providing perverse incentives for the management of the rest of the system. For instance one of the bird species we are focusing on can survive in highly modified environments, so paying only for bird species presence may encourage management practices that do not provide the broader habitat conditions that suit other species of interest. Specifying some inputs or management actions as part of the contract may be useful in these cases. This is more likely to be valuable if the management actions benefit a range of biodiversity outcomes, are required uniformly across sites, are readily verifiable, and only uncertainly connected with the specified outcome.

Another constraint on outcome based payments is the long time lags involved in achieving some biodiversity outcomes, especially when combined with the short funding cycles of government programs. Long time lags may increase the uncertainty of payments to landholders, while limited program time frames may make paying for distant outcomes infeasible.

The limitations of outcome based payments means that in many situations using mixed contracts that specify both outcome and input payments may be of value. This paper examines the policy mechanism design problem for the Nest Egg project. We frame the problem as one of designing a tender system for contracts with a mix of input and outcome contracts that aims to maximise the expected breeding outcome, given a specified budget. The purpose of the analysis is to provide recommendations for auction design, and to understand how the various market failures (hidden information, hidden actions, risk averse land holders) affect the policy design problem.

In the following model we assume that policy makers focus on cost effectiveness, that is they have the simple objective of maximising biodiversity purchases given a fixed budget. The criteria used to evaluate the policy design needs to consider a number of interactions between efficiency and equity effects. When a government agency is purchasing biodiversity as (effectively) a monopoly buyer, the cost effectiveness of the scheme and the efficiency of the scheme can differ in two ways. First any rents accruing to landholders will reduce the cost effectiveness of a tender, however from a welfare perspective these are transfers rather than efficiency effects (however we may need to consider the cost of raising public funds). However, if there are limits on the budget allocated to the scheme, any rents accruing to the landholders will reduce the amount of biodiversity that can be purchased. In this second best world, rents paid to landholders as transfer payments can therefore reduce the amount of biodiversity provided to below its social optimum.

Contribution to the literature

The contribution of this analysis to the literature is to consider how the combination of hidden actions, hidden information, and risk aversion affect the choice of the optimal reward level in a multiple unit auction. In the basic model of hidden actions with no uncertainty, monitoring costs or monitoring errors, pure outcome based payments are most efficient. If uncertainty in production exists, the standard moral hazard result is that, for a risk neutral agent, the optimal level of effort can still be induced by the correct payment schedule provided outcomes are correlated with effort. Ex-ante payment can be used to extract any rents from the agent. However if agents are risk averse, it becomes more expensive to provide them with the incentives via outcome payments. In this situation a mixture of upfront payments and outcome payments form the optimal contract.

Extensions of the moral hazard model to include adverse selection issues are summarised in Laffont and Martimort (2002). In general they find that the contract design implications depend on the timing and structure of the specific problem. The problem of agri-environmental policy design in the presence of both moral hazard and adverse selection issues have been extensively studied (see Fraser, 2002; Hart and Latacz-Lohmann, 2005; Ozanne and White, 2007). The framing of these analyses differ from the current problem in several respects. Notably the production of the environmental good here is considered to be a function of both observable and hidden inputs. The policy design must therefore consider the impacts of policies on the efficiency of the production of the environmental good. The nature of the adverse selection and moral hazard issue, and the type of mechanism under consideration also differ. In particular the moral hazard problem in this literature is typically defined as a compliance problem, whereas here the focus is on setting the incentive levels that will induce the efficient level of hidden actions.

The policy under consideration here is a variation of a multi-unit auction. Auctions of conservation contracts have been studied by Latacz-Lohmann and Van der Hamsvoort, (1997),Stoneham et al 2003, and reviewed by Latacz-Lohmann and Schilizzi (2005). Latacz-Lohmann and Van der Hamsvoort consider the impacts of risk aversion on agents bidding behaviour for contracts on input restrictions. The current study extends this work by considering the possibility of being able to contract on environmental outcomes, and therefore motivate hidden action that are important in achieving them. Auctions of procurement contracts where there are both adverse selection and moral hazard issues have been studied by McAfee and McMillan (1986), and summarised by Laffont and Tirole (1993). The McAfee and McMillan model considers procurement of a single good from multiple bidders who may have differing costs. They focus on the question of what share of realised cost the optimal contract should pay. Their analysis describes how the contract choice involves trade-offs between sharing risk, revealing expected cost information, providing profit margins to encourage competition, and providing incentives to motivate hidden action.

The problem analysed here differs from the McAfee and McMillan analysis in several ways. The selection of multiple sites introduces an additional trade-off between providing landholders with stronger incentives and funding more bids. In addition, in the current problem, effort is expended before the uncertainty is resolved. This means that uncertainty will manifest as a failure to meet the outcome rather than as a cost overrun. This affects the contact design options and the nature of the adverse selection problem. Specifically, the sharing of cost overruns is no longer the key contract design issue. In addition, since cost overruns are no longer shared, selection of low cost providers is no longer an asymmetric information problem in the sense that the principle is not purchasing a contract with cost risk elements. Rather, hidden information problems relate to errors in the ability of the principal to assess the quality of the sites for bird breeding purposes. That is landholders may have private knowledge about the likelihood of bird presence and breeding that they can use to their advantage.

2 Modelling a mixed payment auction scheme

We consider the problem of a catchment management authority (principal) who is trying to maximise the overall breeding success of a bird species with a fixed budget. Three potential contract options span the spectrum of tenders considered here:

1. A tender for inputs or management actions. The landholder specifies the bid price. Payment is condition on input standards being met.
2. An outcome tender, with a fixed payment for achieving an outcome, and an upfront payment specified by the bid for entering the contract.
3. A mixed tender where the amount of a payment for meeting input standards is specified by the bid, and in addition there is a fixed outcome payment conditional on achieving outcome standards.

The upfront payment and the payment for inputs are identical if upfront payments can be reclaimed for failure to meet the contract obligations. The first and second options are therefore subsets of the third with either the input standard removed or the outcome payment set to zero. The analysis therefore focuses on the third option. The key design issues are the choice of the outcome payment price and the input standard.

After defining the structure of the bird production function we consider the problem of landholders (agents) which is to choose a bid and a level of effort to put into hidden actions in order to maximise the benefits they receive from the scheme. Following this we consider the problem of the principal. We begin by considering the problem of risk neutral agents with no hidden information problem. We then consider the impact of risk averse agents and hidden information.

2.1 The bird production function

Consider a land owner's bird breeding production function for a specific site that can support a single breeding event per season. The probability of a successful outcome (denoted by $s_i = 1$) is given by $\pi_i(s_i = 1) = \pi(q_i, k_i, \theta_i)$, where q_i is a measure of intrinsic site quality. This is determined by the innate characteristics of the biodiversity on a site and is outside the control of the landholder. The agent is aware of the absolute value of q_i, however we assume the value of q_i relative to other sites is only known to the principal. k_i is the site condition, it is defined as an observable, verifiable state variable that is a function of landholder investments in the site. We represent input contracts by assuming that a certain site condition $\bar{k}$ is enforced in the contracts. θ_i refers to ongoing management or hidden actions, such as predator control. They are considered to be prohibitively expensive to monitor.

2.2 Agents problem

The timing of the problem is as follows. First the principal announces a outcome price (R) (also called the reward) and asks for tender submissions. The landholders (agents) then calculate their planned level of effort (θ) by solving the production problem specified below, and submit bids with price b_i that will maximise their expected returns. The bid defines the payment made to landholders who are successful in the tender and meet the minimum site condition standard. It is assume to be set by a single round price discriminating auction. By construction the bids will be decreasing functions of site quality (q_i). The principal then chooses a maximum successful bid $\hat{b}$ (or equivalently a minimum successful site quality, $\hat{q}$) which allows the total cost of the scheme to fit within the program budget (B). The principal will evaluate the bids according to their expect cost of achieving breeding success. The expected bid cost (bc_i) is defined by the formula

$$bc_i = \frac{b_i}{\breve{\pi}} + R ,$$

where $\breve{\pi}$ is the principal's assessment of the probability of breeding success.

We assume a pool of agents whose behaviour is defined (for now) by assuming they are risk neutral profit maximisers. Agents costs are assumed to have the form $c_i(k, q_i, \theta_i) = g(k, q_i) + h(\theta_i)$. The form but not the parameters of this cost function are known to the principal. Agent type is defined by their site quality (q_i). There are N agents and their distribution over the range $[0,1]$ is specified by $p(q)$.

The landholders problem is to choose a bid and an effort level to maximise the expected value of the payoff, that is

$$\underset{b,\theta}{Max}\, E\begin{bmatrix} b_i - c_i(k, q_i, \theta_i) + R & bc^m > bc_i, s_i = 1 \\ b_i - c_i(k, q_i, \theta_i) & bc^m > bc_i, s_i = 0 \\ 0 & bc^m < bc_i \end{bmatrix}.$$

The first line defines the payoff when the bid is successful and there is a successful and observed breeding event. The second line defines the pay off when the bid is successful however breeding is unsuccessful. When the bid is unsuccessful the agent receives the value of their outside option for the use of their resources which is normalised to zero. The agents are assumed to have the same prior probability distribution $f(bc^m | I)$about the likely maximum successful bid cost bc^m . Relevant information will include the size of the budget, the size of the reward, their own costs, and their knowledge about the distribution of cost functions of other participants. Evaluating the expectations and grouping terms, the agent's problem can be written as

$$\underset{b,\theta}{Max}\{b_i - c_i(k, q_i, \theta_i) + R\pi(q_i, \bar{k}, \theta_i)\}(1 - F_i(bc_i))$$

This says to maximise the value of the bid, multiplied by the chance that the bid will be successful.

The first order conditions defining the agents behaviour are given by

$$-\frac{\partial c\left(q_i,\bar{k},\theta_i\right)}{\partial \theta}+R\frac{\partial \pi\left(q_i,\bar{k},\theta_i\right)}{\partial \theta}=0$$

$$\left(1-F_i\left(bc_i\right)\right)-\left\{b_i-c_i\left(k,q_i,\theta_i\right)+R\pi\left(q_i,\bar{k},\theta_i\right)\right\}f\left(bc_i\right)\frac{1}{\breve{\pi}}=0$$

The first order condition for the bid choice is often written in the form (Latacz-Lohmann and Van der Hamsvoort, 1997):

$$b_i=-\left\{R\pi\left(q_i,\bar{k},\theta\right)-c_i\left(k,q_i,\theta_i\right)\right\}+\breve{\pi}\frac{\left(1-F\left(bc_i\right)\right)}{f\left(bc_i\right)}$$

Indicating that the bid is equal to the expected cost of participation plus a premium based on information about the expected bid distribution. In this specification the bid premium is also affected by the assessed production value. (The implications of error in this assessed value are discussed later.) The first order conditions reflect a two step optimisation structure to the problem. Effort depends only on the size of the reward, as it is decided only after a successful bid is made, it is therefore independent of the chance of winning the auction and size of the bid. The structure of the agents behaviour can therefore be written as:

$$\theta^*=\theta^*\left(R,q_i,\bar{k}\right)$$

$$b_i^*=b_i^*\left(R,I,c\left(\bar{k},q_i,\theta^*\left(R,q_i,\bar{k}\right)\right)\right)$$

2.3 Principal's Problem

The problem facing the catchment management authority (the principal) is assumed to be to maximise the overall breeding success subject to constraints on its budget, information and the likely behaviour of agents. To do so the principal can choose an outcome reward, R and a minimum site condition $\bar{k}$. To simplify the analysis assume that the landholder can achieve $\bar{k}$ with certainty. The analysis of setting the optimal level of capital is addressed in the next section. We assume a per site monitoring costs of (m) is explicitly borne by the principal. Only those that sign up for the scheme can be eligible for the bonus. We specify the problem as one of choosing a minimum successful initial bid quality $\hat{q}$ that corresponds to a maximum successful bid $\hat{b}(\hat{q})$. The principal's problem can be written as

$$\underset{R,\hat{q}}{Max}\int_{q=\hat{q}}^{q=1}N\pi\left(q,\bar{k},\theta\right)p(q)dq$$

$$st$$

$$N\int_{q=\hat{q}}^{q=1}b_i^*(q,R)p(q)dq+(R+m)N\int_{q=\hat{q}}^{q=1}p(q)dq\le B$$

$$\left(b_i^*,\theta_i^*\right)\in\arg\max\left\{b_i-c_i\left(\bar{k},q_i,\theta_i\right)+R\pi\left(q_i,\bar{k},\theta\right)\right\}\left(1-F_i\left(bc_i\right)\right)$$

That is, maximise the overall breeding success, subject to the budget constraint and the bidding and effort behaviour of the participants. The budget constraint limits total expenditure which is the expenditure on bids, plus reward and cost of monitoring times the number of successful applicants. We assume that the budget constraint must be set conservatively, that is assuming all bids have successful breeding. The optimising behaviour of agents defines the agents bid and effort as a function of the reward and the initial site quality.

To analyse the properties of the solution substitute the agents biding behaviour into the budget constraint and define the cut-off quality value $\hat{q}$ as a function that solves the budget constraint for a specified R and biding behaviour. That is:

$$\hat{q}^* = \hat{q}^*\left(R+m, B/N, b_i^*\left(R, I, g\left(q,\bar{k}\right)\right), p(q)\right)$$

Next substitute the agent behaviour and $\hat{q}^*$ into the objective function to get

$$\underset{R}{Max}\int_{q=\hat{q}^*}^{q=1} N\pi\left(q,\theta^*,\bar{k}\right)p(q)dq$$

The first order condition of this problem is given by differentiating with respect to R to get:

$$\int_{q=\hat{q}^*}^{q=1} p(q)\frac{\partial\pi\left(q,\bar{k},\theta^*\right)}{\partial\theta}\frac{\partial\theta^*}{\partial R}dq - \pi\left(\hat{q}^*,\bar{k},\theta^*\right)p\left(\hat{q}^*\right)\frac{\partial\hat{q}^*}{\partial R} = 0$$

The first term of this expression is the marginal benefit of increasing the reward. It is the benefit from the increased effort due to paying a higher reward to those already funded. This value needs to be equated with the opportunity cost of increasing the reward, the value of which is given by the second term. This is the breeding value of the extra bids that cannot be funded as a consequence of increasing the reward. More precisely it is the value of the marginal bid times the number of extra bids that can be purchased if the reward is decreased.

Examining how the value of both terms change with the reward defines the trade-offs involved in choosing the appropriate reward. The second derivate with respect to the reward provides this information. It is given by:

$$\begin{aligned}\frac{\partial V}{\partial R\partial R} &= \int_{q=\hat{q}^*}^{q=1}\left[\frac{\partial^2\pi}{\partial\theta\partial\theta}\frac{\partial\theta^*}{\partial R}\frac{\partial\theta^*}{\partial R} + \frac{\partial\pi}{\partial\theta}\frac{\partial^2\theta^*}{\partial R\partial R}\right]p(q)dq \\ &- \frac{\partial\hat{q}^*}{\partial R}p\left(\hat{q}^*\right)\left[\frac{\partial\pi}{\partial\theta}\frac{\partial\theta^*}{\partial R}\right] \\ &- \frac{\partial\hat{q}^*}{\partial R}p\left(\hat{q}^*\right)\left[\frac{\partial\pi}{\partial q}\frac{\partial q}{\partial\hat{q}^*}\frac{\partial\hat{q}^*}{\partial R} + \frac{\partial\pi}{\partial\theta}\frac{\partial\theta^*}{\partial R}\right] \\ &- \frac{\partial^2\hat{q}^*}{\partial R\partial R}\pi\left(\hat{q}^*,\theta^*\right)p(\hat{q}) \\ &- \frac{\partial\hat{q}^*}{\partial R}\pi\left(\hat{q}^*,\theta^*\right)\frac{\partial p\left(\hat{q}^*\right)}{\partial\hat{q}}\frac{\partial\hat{q}^*}{\partial R}\end{aligned}$$

The first two lines relate to the change in the benefits as the reward increases. The first line says the benefits of extra effort are a decreasing function of the reward due to the curvature of the production and cost functions. In additional the second line says that the benefits are a decreasing function of the reward, since at higher reward levels fewer bids are funded. The last three lines can be interpreted as the change in the marginal opportunity cost of unfunded bids with changes in the reward. In general these terms are negative, indicating that the opportunity costs are increasing with the reward level. Line three describes the increase in opportunity cost of unfunded bids with reward due to the increased effort and quality of the marginal bid as the reward increases. Line four captures the effect of changing the reward level on the relative cost of acquiring a new site. This can be thought of as the slope of the budget constraint that describes how many sites can be bought given the cost of each in terms of the bid and the reward. The slope of the budget constraint is given by

$$\frac{\partial \hat{q}}{\partial R} = \frac{\int_{q=\hat{q}}^{q=1} \left[1 + \frac{\partial b_i^*(q,R)}{\partial R} \right] p(q) dq}{\left(R + m + b_i^*(\hat{q},R) \right) p(\hat{q})}$$

This is positive and tends to zero at high rewards for two reasons. First, at high reward levels, the number of participants is lower, so increasing the reward has a smaller impact on the budget. Second the bid size decreases when rewards increase. For marginal cost bidding the change in the bid with the reward is given by

$$\frac{\partial b_i}{\partial R} = -\gamma \pi \left(q_i, \theta^*(R) \right)$$

At higher rewards, the successful agents expect to be more successful because they have high quality sites and high effort levels. Therefore they are more willing to lower their bids in response to an increase in the reward. In the extreme, if breeding is guaranteed, bids will go down by one dollar for every dollar increase in the reward. In this case changing the reward will have no effect on the number of bids that can be funded. The last line describes the effect of the change in the density distribution of bids with the reward and is of an indeterminate sign. For a uniform distribution of bids it is zero.

Simulation results

To illustrate these results a parameterised version of this model was implemented in excel. Figure 1 illustrates the effects of changing the reward level. Note that the maximum outcome is (approximately) where the maximum bid is zero. At this point the outcome payment is providing the main price signal, and therefore produces an efficient mix of land and effort. This result is only approximate as the distribution of site quality across landholders affects the optimal outcome payment. Also note that, as discussed, the number of successful bids declines more slowly at higher reward levels. In addition to the response of bid prices to the reward identified above, the cost function curvature conditions ($c'' > 0$) mean that at higher reward levels an increase in reward induces a smaller effort increase. This inelastic response at high reward levels means that less of the extra reward money is spent on increasing effort and more is producer surplus, and this is recycled into lower bids. The practical implication of this is that if the optimal effort level is expected to be at an inelastic part of the response curve, then setting the reward on the high side is a safe bet. In contrast setting the reward too low produces a steep decline in net benefits as the level of effort is below optimal, and the budget is spent instead on adding more low quality sites. Therefore, in setting the reward, there is a combined effect of the reward on site quality and effort that, given uncertain cost estimates, favours setting higher reward levels.

2.4 Risk averse agents

Consider now an agent population that discounts the value of the reward because of the uncertainty associated with achieving it. A complete analysis would account for the risk associated with the outside option, and a risk diversification role of spreading income options. For now we wish to focus on the fact that the reward payment is uncertain. Following (Latacz-Lohmann and Van der Hamsvoort, 1997) we consider the decision of risk averse land owners who value an uncertain reward by calculating the expected pay-off and deducting a risk premium (RP). The risk premium is a function of the reward and a subjective assessment of the probability of success. That is

$$RP = RP\left(R, \pi\left(q_i, \bar{k}, \theta_i\right)\right)$$

The agents problem can be written as

$$\underset{b,\theta}{Max}\, E\begin{bmatrix} b_i - c_i\left(k, q_i, \theta_i\right) + R - RP & bc^m > bc_i, s_i = 1 \\ b_i - c_i\left(k, q_i, \theta_i\right) & bc^m > bc_i, s_i = 0 \\ 0 & bc^m < bc_i \end{bmatrix}$$

Taking expectations the result is:

$$\underset{b,\theta}{Max}\left\{b_i - c_i\left(\bar{k}, q, \theta\right) + \left(R - RP\right)\pi\right\}\left(1 - F_i\left(bc_i\right)\right)$$

The first order conditions defining the agents effort is given by

$$-\frac{\partial c\left(q_i, \bar{k}, \theta_i\right)}{\partial \theta} + \left(R - RP\right)\frac{\partial \pi}{\partial \theta} - \pi \frac{\partial RP}{\partial \pi}\frac{\partial \pi}{\partial \theta} = 0$$

This effort will be less than the risk neutral case if

$$RP + \pi\left(q_i, \bar{k}, \theta_i\right)\frac{\partial RP}{\partial \pi} > 0.$$

That is, the risk premium decreases the incentive value of the reward, however this effect is countered if the landholder expends effort to reduce the risk premium by increasing the chance of success. The effect of the risk premium on bidder behaviour is given by the first order condition:

$$\left(1 - F_i\left(bc_i\right)\right) - \left\{b_i - c_i + \left(R - RP\right)\pi\right\}\frac{1}{\bar{\pi}} f_i\left(bc_i\right) = 0$$

The direct effect of the risk premium on the bid is therefore to reduce the perceived value of the reward and therefore require a higher bid price in order to participate. Indirectly risk aversion also affects the bid via its impact on effort and expected outcome as discussed above.

Analysis of the impact of risk aversion on the principal's problem is left for future work. However, assuming that the direct effect of risk aversion on reducing effort and increasing bids dominate, risk aversion should reduce the optimum reward level. That is the optimum solution will move towards signing up more landholders, and reducing hidden actions compared with the risk neutral case. If risk aversion makes contracting on outcomes expensive then it may be worthwhile also contracting on inputs where the cost of risk aversion is not incurred. The next section therefore looks at the implications of imposing input requirements as part of the contract.

2.5 Landholder behaviour with fixed inputs

This section provides a graphical analysis of the implications of mixed incentives on the behaviour of landholders. Specifically it looks at how agents will respond to outcome payments when up front payments (the bid price) are conditional on fixing observable (capital) inputs at a prescribed level. The analysis uses the terminology of long run and short run behaviour that is standard in introductory economic analysis of capital fixity. However, in this case the level of the capital input is fixed by regulation rather than by the time horizon. Figure 2 describes the marginal and average cost of providing a product (in our case bird breeding services), when production requires a mixture of capital and variable inputs. It shows a hypothetical marginal cost curve when the capital level can be changed in order to minimise costs. This is the long run marginal cost curve (lrmc) and the corresponding long run average cost of production (lrac). Figure 2 also show the cost curves when the capital level is fixed at k^*, which is the cost minimising level of capital for producing $y(k^*)$. These are labelled as short run marginal cost (srmc) and short run average cost curves (srac). The short run average variable cost curve is also shown (sravc).

Assume that the principal decides to set a minimum capital level at k^*. If the outcome payments are set at p^* or higher then this restriction will not affect the agent, as they would maximise profits by choosing a higher capital level. Note however that if the principal decides to set the outcome payment below p^*, say at p^o the short run marginal cost in this region is in fact lower than the long run curve. This reflects the fact that the fixed costs are no longer factored into the marginal costs. Setting the output payment to p^o would result in output of y^l if capital is not fixed, and y^s if the capital level is fixed. Fixing the level of capital therefore increases the level of production for output prices below p^*.

The relevance of this analysis is that the principal may be able to reduce the cost to the program of risk aversion by lowering the reward price but insisting on a high fixed level of capital. There will be inefficiencies in doing so equal to the difference between long run average and short run average costs at y^s. The benefit of doing so is that a higher level of effort will be induced for any given reward level. In addition, the use of an input standard may allow the principal to overcome the other cost of reducing the reward, which was that it resulted in enrolling lower quality sites.

The analysis can also be used to examine the effects of the bonus on the need to monitor inputs. If the profit from using the capital in production, $(p^o - sravc^o)y^s$ is greater than the outside value of the capital, then the landholder will be better off investing it as promised rather than keeping the money. There is, however still an incentive to limit investment in capital to the long term optimal level corresponding to p^o. However the outcome payments will reduce the payoff to cheating on the capital investment, and therefore should reduce the monitoring costs.

2.6 Hidden information

The principal will in general only be able to measure and model the value of a site as habitat imperfectly. Landholders, by virtue of having observed the breeding history on their land may well have private information about the potential breeding success. This section considers the implication of this measurement error for the design of an outcome incentive.

We assume that quality of the site q_i is known to the agent, however the site quality is assessed by the principal to be $\breve{q}_i = q_i(1+e_i)$. Assume the principal judges the likely breeding success and effort level on the basis of the measured site quality. Define $\breve{\pi} = \pi(\breve{q}, \bar{k}, \theta^*(\breve{q}))$ as the principal's estimate of the chance of successful breeding, given a site assessment of $\breve{q}$. As above, bids are then compared on the basis of cost per expected breeding outcome, and the cost per expected breeding outcome for a site with assessed site quality $\breve{q}$ is given by:

$$bc_i = \frac{b_i}{\breve{\pi}} + R\,,$$

Note that if the payment is only for outcomes, that is $b_i = 0$, then the evaluation of site quality, and therefore any error in this evaluation, has no impact on the evaluation of the bid. In other words there is no need to evaluate the quality of the site attributes if landholders are only paid for outcomes. It is also possible to say something about how the error will affect bidding behaviour. As derived above the first order condition defining the agents bid is

$$b_i = -R\pi(q_i, \bar{k}, \theta) + c_i(k, q_i, \theta_i) + \breve{\pi}\frac{(1-F(bc_i))}{f(bc_i)}$$

This states that the error in the measurement of site quality affects the premium that the agents adds to their bids. Defined in terms of the bid cost the first order condition is

$$bc_i = \frac{c_i(k, q_i, \theta_i)}{\breve{\pi}} + R\frac{(\breve{\pi}-\pi)}{\breve{\pi}} + \frac{(1-F(bc_i))}{f(bc_i)}$$

In this interpretation, the expected bid cost that landholders charge will equal the costs adjusted for expected production plus the reward times the scaled error in assessed production, plus the bid premium.

In order to examine the effect of measurement error on the bid amount, apply the implicit function theorem to the first order condition for the bid amount. The result is:

$$\frac{\partial b_i}{\partial \breve{\pi}_i} = \frac{2b_i - oc_i + \{b_i - oc_i\}\dfrac{b}{\breve{\pi}^2}\dfrac{f'(bc)}{f(bc)}}{2\breve{\pi}_i + \{b_i - oc_i\}\dfrac{f'(bc)}{f(bc)}}$$

Where $oc_i = -R\pi(q_i, \bar{k}, \theta) + c_i(k, q_i, \theta_i)$ is the opportunity cost of participation. Consider the case where $f'(v) = 0$, for instance if the expectation distribution has a uniform distribution, or if agents have normally distributed expectations and believe their costs are average. This expression then simplifies to:

$$\frac{\partial b}{\partial \breve{\pi}} = \frac{2b - oc_i}{2\breve{\pi}}\,.$$

Since the bid is greater than the opportunity cost, this states that bids increase with an increase in assessed production. The change in the evaluated bid cost with a change in the assessed production value can also be calculated. It is:

$$\frac{\partial bc}{\partial \breve{\pi}} = -\frac{oc_i}{2}.$$

If the reward is set low enough to permit cost sharing, the opportunity cost is positive and this result suggests that while landholders will submit higher bids if the site assessment is erroneously high, the bids will appear to be at a lower cost. This result suggests that there will be a selection bias due to the error in measurement. That is, imperfect assessment will result in landholders with positive errors (i.e. favourable assessments) submitting lower value bids that are more likely to be selected. The distortion in bid costs will be minimised by setting the reward such that the expected opportunity cost is zero.

Formal analysis of how knowledge that there is an error in the site assessment affects the optimal auction design is left for future work. This analysis suggests however that errors in the ability to assess site productivity makes getting the reward price right more important, as it increases the cost of setting it too high or too low. For situations where we are interested in setting a low reward price in order to permit risk sharing, the presence of asymmetric information increases the cost of risk sharing.

3 Discussion

The objective of this analysis is to guide the design of tender based mechanisms where hidden actions as well as variable site qualities affect the environmental outcome, in this case bird breeding. The first result is that in setting an outcome price the budget constrained principal is implicitly choosing both the level of effort and (via the budget constraint) the number of bids that can be funded. Efficiency requires that the marginal benefits of both inputs are equated, and this is achieved when the upfront (bid) payment is approximately zero. This provides some guidance in setting the outcome payment price, however doing this would require knowing the correct price, and one of the purposes of the auction is price discovery. Taking account of the uncertainty surrounding the outcome price is therefore important.

The analysis suggests that the cost of setting the outcome payment level too high are less than the costs of setting it too low. This results stems from the nature of the relatively complex trade off involved in choosing a level of reward. Higher rewards mean fewer participants, however the high reward means the participants that are involved are more highly motivated and have higher quality sites. Bidding behaviour also changes with the reward level and this affects the budget constraint. Since bids are determined by the expected reward, if success is likely, then the budgetary cost of increases in the reward level is offset by lower bid amounts. These factors mean there is only a relatively small cost of setting the reward price too high. Conversely setting a outcome payment to a low price such that landholders require an upfront payment to enrol has multiple and compounding impacts on the cost effectiveness of the auction. Lowering the reward results in accepting more lower quality sites and landholders providing less effort. There is also less revenue recycling at low outcome payments, as a greater fraction of the marginal payment is spent on effort. The combination of these factors means that setting the outcome payment to a level below the efficient level can therefore have a significant impact on the efficiency of the tender.

The analysis shows that hidden information results in landholders with favourable assessments submitting bids that appear to be better value than they would if the assessments were correct, however the bids are in fact of lower value. The presence of hidden information, due to the inability of the principal to model the biodiversity outcomes perfectly, therefore increases the importance of setting the outcome payment to the efficient level. Intuitively at prices above or below the efficient price the principal is relying on this imperfect information to select sites and is paying or receiving bid payments on the basis of this information.

These results also address a perception that the inability to model and predict environmental outcomes well is a serious limitation to the use of markets, (and outcome based markets) to achieve environmental outcomes. For instance:

"information requirements of bio-physical models makes it difficult to develop MBIs that are defined in terms of ambient or environmental outcomes rather than the measurable actions or inputs of landholders" (Grafton 2005).

… it is difficult just to predict the biodiversity consequences of different interventions, let alone their values. If tenders are to really … achieve their potential, we will need to greatly improve knowledge about cause and effect relationships for interventions and their consequences for biodiversity. I suspect that this may be the biggest single factor inhibiting improved purchase of environmental services, whether we use tenders or other approaches. (Pannell, 2007)

These results indicate however, that paying for biodiversity outcomes reduces the need to rely on the predictions of models in order to choose the best sites and to decide on the preferred management strategies. If it is possible to define and contract on biodiversity outcomes, it will therefore overcome a major obstacle to purchasing biodiversity and environmental services. There is still a need for knowledge of how to manage for improved biodiversity. However outcome based biodiversity markets do not require this knowledge of the biodiversity "production function". In fact they provide incentives for landholders and scientists to collaborate in generating it.

The paper also begins to analyse the possibility of using a mixed input and outcome based contact to reduce the program cost of risk aversion among landholders. The paper makes two inroads into analysis of this problem. First it considers the impact of requiring observable inputs to be fixed at a given level on the response of production to output prices. Fixing the (observable) input level is shown to reduce the marginal cost of production and therefore increases production for a given output price. Imposing a minimum standard on observable inputs may therefore reduce the inefficiency of reducing the outcome price. The second inroad is to consider the impact of risk aversion on agents bidding and production behaviour. Risk aversion is modelled as a risk premium that reduces the incentive value of the uncertain outcome payment. Risk aversion therefore reduces effort. However risk aversion is also shown to have a second, compensating effect. That is, it induces agents to increase effort in order to reduce the uncertainty of the outcome payment. Further work is required to establish which of these risk effects dominate, if other risk considerations are important (such as those associated with the outside option), and to model under what conditions an input standard may be justified in a tender with outcome payments.

Several issues that have not been modelled may also be important in the design of tenders with outcome payments. Monitoring of outcomes is expensive, and can be subject to significant measurement error. However both input based contracts and outcome based contracts require monitoring and enforcement. The doubling up of monitoring costs suggests that mixed contracts require strong synergistic benefits in order to be justified. High monitoring costs could therefore favour a single instrument (either inputs or outcomes). However monitoring synergies may be important. In particular the use of an output contract should reduce the need for monitoring of inputs, and therefore the cost of doing so. In addition, outcomes and inputs may be monitored at the same time, reducing the additional cost. High outcome monitoring costs may therefore not be as much of an obstacle to outcome based payments as they first appear.

Paying for outcomes also allows flexibility in how they are achieved and is also likely to encourage innovation that will allow the desired outcomes to be achieved more efficiently. Flexibility is likely to be important as heterogeneity in farming and ecological systems mean that management approaches need to be tailored to the location.

Outcome payments may also affect landholders intrinsic motivation to provide biodiversity outcomes. An outcome based tender system could have multiple and conflicting impacts on intrinsic motivation. For example the outcome incentive could increase landholders understanding of the breeding requirements. It is possible that this increased awareness would also increase the personal utility derived from the improved habitat. Conversely the payment for outcomes, or more specifically the threat not to pay may be seen as a signal of lack of trust. In addition the lack of payment for situations where either observational error or random outcomes prevent payment when hidden action were in fact carried out may decrease the sense of personal ownership and responsibility for management. Other impacts on intrinsic motivation are also possible. However these two examples illustrate how outcome payments may either increase of decrease intrinsic motivation. It is possible that intrinsic motivation issues.

This paper has provided some theoretical background to the design of the Nest Egg tender. This trial aims to improve our understanding of how the range of factors identified in this paper influence the effectiveness and efficiency of tenders with outcome payments. As of September 2007, the tender has closed the call for expressions of interest, and site inspection are in progress. Future research on this trial will focus on evaluating bidding behaviour, and the effect of the outcome based payments on breeding outcomes, non-verifiable effort and learning and innovation.

4 References

Fraser, Rob. "Moral Hazard and Risk Management in Agri-environmental Policy". *Journal of Agricultural Economics* 53(2002): 475-487. .

Grafton, R. Q. Evaluation of round one of the market based instrument pilot program, Report to the National Market Based Instrument Working Group. 2005.

Hart, Rob and Latacz-Lohmann, Uwe. "Combating moral hazard in agri-environmental schemes: a multiple-agent approach". *Eur Rev Agric Econ* 32(2005): 75-91.

Laffont, Jean-Jacques and Martimort, David. The Theory of Incentives: The Principal Agent Model. 2002. Princeton and Oxford, Princeton University Press.

Laffont, Jean Jacques and Tirole, Jean. A Theory of Incentives in Procurement and Regulation. 1993. Cambridge, Massachusetts London, England, The MIT Press.

Latacz-Lohmann, Uwe and Schilizzi, Steven. Auctions for conservation contracts: A review of the theoretical and empirical literature. 2005. Report to the Scottish Executive Environment and Rural Affairs Department

Latacz-Lohmann, U.L. and C. Van der Hamsvoort. "Auctioning Conservation Contracts: A Theoretical Analysis and an Application ." *American Journal of Agricultural Economics* 79(1997):407-718.

McAfee, R.P. and J. McMillan. "Bidding for contracts: a principal-agent analysis." *Rand Journal Of Economics* 17(1986):326-338.

Ozanne, A. and B. White. "Equivalence of Input Quotas and Input Charges Under Asymmetric Information in Agri-Environmental Schemes." *Journal of Agricultural Economics* 58(2007):260-268.

Pannell, D. P. A National Market for Biodiversity? http://cyllene.uwa.edu.au/~dpannell/pd/pd0102.htm Accessed November 2007.

Stoneham, G., V. Chaudri, A. Ha, and L. Strappazon. "Auctions for conservation contracts: an empirical examination of Victoria's Bush Tender Trial." *The Australian Journal of Agricultural and Resource Economics* 47(2003):477-500.

Figure 1 Simulated results for the breeding outcome, fraction of successful tenders, average effort and maximum successful bid as a function of the outcome payment

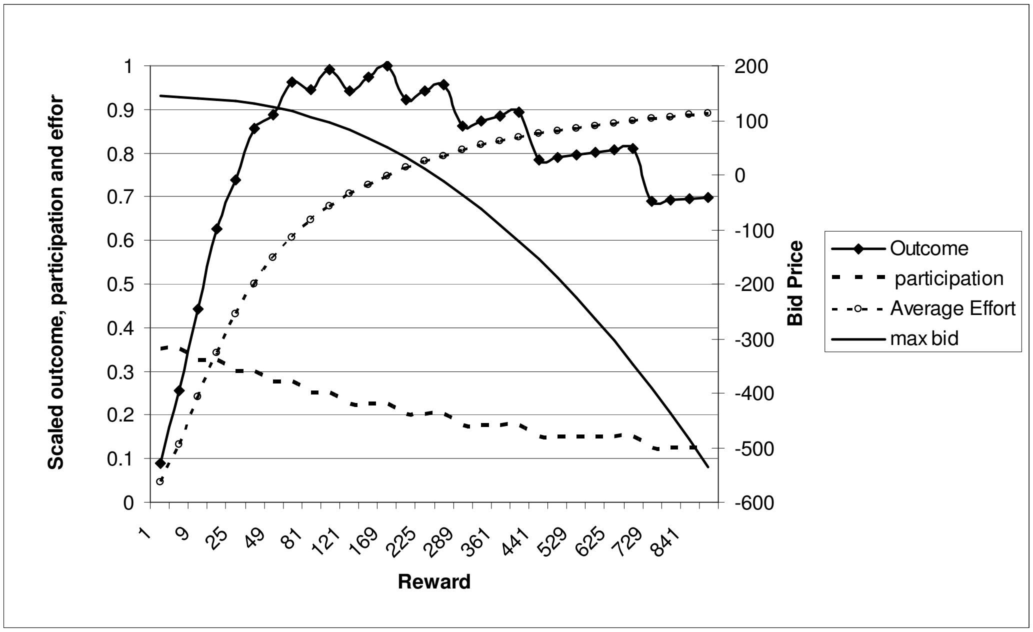

Figure 2 The impact of fixing capital inputs on the cost of production