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# Should We Pay for Ecosystem Service Outputs, Actions or Both?

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# Should We Pay for Ecosystem Service Outputs, Actions or Both?


Abstract

*Payments for ecosystem service outputs have become a popular policy prescription for a range of agri-environmental schemes. The focus of this paper is on the choice of sets of instruments in an ecosystem service principal-agent model that addresses adverse selection and moral-hazard. Results show that input-based and output-based contracts are equivalent where there is full information. With missing information, input-based contracts are more efficient at reducing the informational rent related to adverse selection than output-based contracts. There is an efficiency gain related to using mixed contracts especially where one input is not observable. These contracts allow the regulator to target variables that are costly-to-fake as opposed to those prone to moral hazard such as labour inputs. We then consider the implications of moral hazard and dynamic contracting. An overall finding is that in designing agri-environmental schemes, it is critical that the regulator has an understanding of the link between actions and ecosystem service outputs and, ideally, an estimate of their economic value. Without these in place, payment for ecosystem service schemes will be inefficient and poorly targeted.*

# 1 Introduction

The provision of ecosystem services and biodiversity conservation can be analysed as a process of accumulating and maintaining ecosystem assets. In other words it is an investment decision that requires diverting land, labour and man-made capital to a capital accumulation process. For instance, in the case study discussed later in this paper, the ecosystem asset is an area of native vegetation of a particular conservation value. Without sufficient land and effort allocated to its protection, vegetation will continue to degrade (depreciate) through time. If the vegetation remnant is recruited into a conservation management scheme then both the area and its condition or quality may increase over time – a form of capital accumulation. The definition of ecosystem services used here is consistent with Bateman et al (2011), Barbier (2009) and Mäler et al. (2009). To quote Bateman (2011, p180) "*the level of ecosystem service 'harvested' within any given period can be thought of as a 'flow' extracted from an underlying 'stock' of ecosystem asset….*" Thus ecosystem services are a function of ecoystem assets and other inputs.

Since the objective of Payment for Ecosystem Service (PES) schemes is to increase the supply of ecosystem services and biodiversity, an obvious question is whether payments should be targeted at outcomes (better water quality, more plant species) rather than at the management actions leading to such outcomes (Hanley et al, 2012). Most current agri-environmental policy is targeted at management actions, typically because these are thought easier to observe, and because the 'output' of biodiversity from a given area of land is determined by a wide range of factors, only some of which are under the direct control of the landowner. This means that outcome-based contracts are riskier for the landowner than action-based contracts (Whitten *et al*., 2007). Moreover, it may be more expensive for the regulator to monitor conservation outcomes (e.g. counting birds) compared to management actions (e.g. whether a landowner has drained a wetland or not).

However, outcome-based payments have their advantages (Gibbons *et al*., 2011). If some of the management actions which are crucial to achieving a biodiversity target are hidden (expensive for the regulator to observe), then paying for outcomes may be more efficient. Landowners and managers quite likely hold information on the best areas of land within their properties for promoting target species populations, and may have alternative options for encouraging such increases in species. Outcome-based payments encourage land managers to make use of this information to generate biodiversity conservation more efficiently than payment for actions. Finally, such contracts incentivise unobserved or unobservable inputs such as conservation effort expended by the land manager.

The aim of this paper is to set up a general model of contracting that accounts for many of the attributes of the agri-environmental problem and then explores the optimal selection of policy instruments for a set of simplified special cases. Given the potential complexity of a model with two inputs, one of which may be unobservable, we restrict attention to a simple principal agent setting: two producer types, differentiable functions and a simple treatment of the issues of risk aversion and dynamic contracting. The approach is for voluntary agri-environmental schemes based around a mechanism design approach to structuring contracts to induce a dominant-strategy equilibrium in games of incomplete information. The mechanism applied is a menu of contracts that is able to separate farm types as a way of reducing information rents.

## 2 Literature Review

Burton and Schwarz (2013) note that, although there is often a call for ecosystem service schemes to be switched from the input- or action- based design widely implemented in many European, North American and Australian agri-environmental programmes to outcome-based or result orientated schemes, rather little evidence exists on the performance of such outcomes-based schemes to support such a recommendation. In part, this is because their use to-date has been rather limited, in the sense that there are few nation-wide examples of outcomes based schemes, since applications have mainly been regional initiatives (within German *lander* for instance). Moreover, of those schemes which have been implemented, payments for actions and/or regulations of actions often accompany payments for results. Moreover, there are no evaluations which rigorously measure outcomes using the kinds of impact analysis techniques employed for example by Miteva et al (2012).Thus, so far there is little evidence that this change in contract design would be more effective than the current input-based approach.

Weitzman (1974) stated that the "..average economist in the Western marginalist tradition has at least a vague preference toward indirect control by prices, just as the typical non-economist leans toward the direct regulation of quantities." (p 477). He shows equivalence between setting the price of a good or service and leaving the firm to maximize the profit by adjusting the output; or fixing output and leaving the firm to minimize costs. He then states that any advantage of one policy over another must " be due to inadequate information or uncertainty." This paper and the literature on procurement and contracting that followed (Laffont and Tirole, 1993; Laffont and Martimort, 2001) have led to a large number of papers specifically concerned with the design of agri-environmental polices (see Wu and Babcock, 1996; Moxey, Ozanne and White, 1999) for a review see Ferraro, 2008 and Hanley et al 2012).

Recent papers that have specifically looked at the optimal selection of alternative policy mechanisms include Melkonyan and Taylor ( 2013). They show in relation to policy for US ranchland that given informational asymmetries between ranchers and regulators, outcome based payments are a first-best policy when regulators can perfectly monitor the ecological condition of the ranch. Where monitoring is imperfect, input regulation and cost-sharing or taxation may dominate performance regulation. Anthon et al (2010) consider the optimal design of PES-type contracts to private landowners under asymmetric information for the Natura 2000 policy.

Derissen and Quaas (2013), extending a model by Zabel and Roe (2009) develop a mixed performance-based and action based contracting approach to a contract setup where the farmer is better informed about environmental performance than the regulator. There model addresses asymmetric information relating to the marginal productivity of the "ecosystem production function". Their paper does not allow for more than one "action" or address adverse selection. They show that a mixed contract on actions and output is optimal.

This paper uses a two producer type model, building on Khalil and Lawarree, (1995), to compare an input-based ecosystem service scheme to an outcome-based scheme, and a mixed contract. The focus of the paper is adverse selection, arguably the most significant source of information rents and additional cost in current agri-environment and other PES policies (Moxey et al. (1999); Wu and Babcock (1996); Ferraro (2008)). The point of departure in this paper is that the farmer produces the ecosystem service outcome using two inputs: land and effort. Typically, one of these inputs is more costly for the regulator to observe than the other. In most principal-agent models it is assumed that there is a single input effort, see Laffont and Martimort (2002) for a general review and (Laffont and Tirole, 1993) for a review relating to models of procurement. Our model allows for input-based, outcome-based and mixed contracts to be offered by the regulator to the landowner in return for payment. We can thus compare the relative merits of these three alternative policy designs. The paper then considers the additional complications of moral hazard, risk aversion and dynamic contracts. Throughout, we talk about contracts which incentivise farmers to "produce" a desirable ecosystem service (ES), such as flood prevention or carbon sequestration, but the analysis carries over to farmers being offered incentives to conserve or enhance wildlife on their land.

## 3 Model

This section sets up a general model of ecosystem service contracting, and then explores aspects of the model to assess when payment for ecosystem output or payment for ecosytem inputs is optimal. Assume that there are just two representative farmer types that are able to provide ecosystem services related to land management in a region. These types differ according to their agricultural productivity, on which information may be hidden from the regulator. Thus there is hidden variation in the opportunity costs of providing ecosystem inpus, since the production of ecosystem services requires the sacrifice of inputs used to produce profitable crops. Farmers combine land and effort to “produce” an ecosystem output. These benefits can be measured by environmental scientists and ecologists and summarised as a metric; and can then be valued by economists in monetary units. The contract timing for this problem is given in Figure 1 and follows Laffont and Martimort (2002, p33).

Aspects of the standard model that are explored here include the number of inputs, farm types and information. The standard model, for instance Laffont and Martimort (2002,Chapter 3) typically has a single input variable “effort”. This simplification is questionable when there are multiple inputs used to produce the ecosystem service. Here one input is typically observable, for instance land use, and another is not, typically effort which includes manual labour and managerial input. If there are two inputs, then the farm’s type may relate to land or effort productivity, overall cost of producing ecosystem output or behavioural parameters such as risk aversion and time preference. The standard model does not include the possibility that the regulator could select to monitor another variable – such as ecosystem output as a way of improving contracting. This is discussed for a one input model by Khalil and Lawarree, (1995). We follow the approach of Bolton and Dewatripont (2005) where complex contracual settings are analysed with relaltively simple models. This approach is complemented by reference to an empirical example. The start of each section gives the assumptions about the contractual setting and the results at the end of each subsection the main results from the simple model.

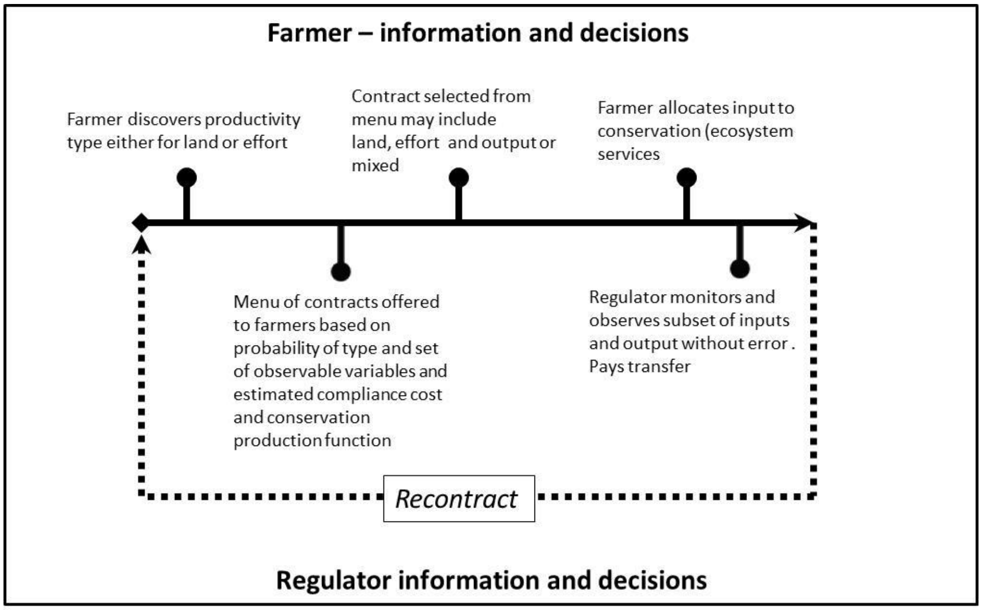



**Figure 1 Contract timings**

## 3.1 Compliance costs

The costs of engaging in providing an ecosystem service are internal to the farm business in the sense that the farmer allocates resources within the business to provide the ecosystem service, thus land and effort is re-allocated within the business and has a strictly convex opportunity cost. The restricted profit function (Lau, 1976) with a fixed land and effort is: $\pi^0 = \pi(\theta_i^x, \theta_i^e, p^a, w^a, \bar{x}_{ti}^a, \bar{\mathrm{e}}_{ti}^a)$ where $\pi^0$ is the baseline agricultural profit (see Table 1). Here, θ is the farmer's type (defined on either land productivity $\theta_i^x$ or effort productivity $\theta_i^e$), $p^a$ are crop output prices, $w^a$ is the price of variable inputs such as fertilizer, and $\bar{x}_i^a$ and $\bar{\mathrm{e}}_i^a$ are respectively land and effort allocated to agriculture. The productivity parameters and prices are assumed to be fixed. Each farmer can identify the optimal profit from farm production and allows the profit maximising choice of other variable inputs such as pesticides and fertilizers. The restricted profit function provides a way of describing a *compliance cost function* where resources $x_i$ (land) and $e_i$ (effort) are re-allocated from crop production to conservation:

$$c(\theta_i^x, \theta_i^e, x_{ti}, \mathrm{e}_{ti}) = \pi^0 - \pi(\theta_i^x, \theta_i^e p^a, w^a, \bar{x}_{ti}^a - x_{ti}, \bar{\mathrm{e}}_{ti}^a - e_{ti}) \tag{1}$$

Compliance cost is thus baseline agricultural profit less agricultural profit with a proportion of land and effort allocated to providing the ecosystem service. To make the analysis tractable we assume that the compliance cost function (1) is approximated by the following separable convex form:

$$c(\theta_i^x, \theta_i^e, x_{ti}, \mathrm{e}_{ti}) = c_x(\theta_i^x, x_{ti}) + c_e(\theta_i^e, e_{ti}) \tag{2}$$

The opportunity cost of land and effort is convex and allocating land and effort beyond the farm's current endowment to the ecosystem output is not expected to be the case but can be allowed in the current framework. It is convenient to assume that this cost function is homogenous in inputs, as this makes results clearer as the ratio of land to effort is independent of scale.

**Table 1 about here**

## 3.2 General contracting problem

This section sets up the general contracting problem as a basis for considering the potential for different contract designs given the information available to the regulator. The risk neutral regulator maximises a social welfare function defined as:

$$\underset{x_{ti}, e_{ti}, f_{ti}, p_{it}}{Maximum} \sum_t \sum_i \delta^t \phi_i \begin{Bmatrix} vg(x_{ti}, e_{ti}, \mathrm{y}_{t-1i}) - c_e(\theta_i^e, e_{ti}) - c_x(\theta_i^x, x_{ti}) \\ -(1+\lambda)\mathrm{c}_m(e_{ti}, x_{ti}) - \lambda(f_{\mathrm{ti}} + \mathrm{p}_{it}\mathrm{y}_{ti}) \end{Bmatrix} \tag{3}$$

The term $\delta^t$ is the regulators discount factor where $t$ is time and $\phi_i$ is the probability of a given firm being of type *i*.[1] The regulator maximizes the expected present-value of the ecosystem output given by the difference equation that describes the ecosystem production function $\mathrm{y}_{ti} = g(x_{ti}, e_{ti}, \mathrm{y}_{t-1i})$ for farm type *i*, where *v* is the economic value per unit of increase in the ecosystem asset. The term $\mathrm{c}_m(e_{ti}, x_{ti})$ is an administrative cost to address moral hazard through compliance monitoring. Policies can include direct contracts for land, effort or output. The farmer receives payments either as lump-sum transfers $f_{ti}$ and/or as a per unit of output payment $\mathrm{p}_{ti}\mathrm{y}_{ti}$. In the social welfare function, transfers are weighted by the shadow price of public funds $0 \le \lambda \le 1$. This term accounts for the cost of raising tax revenue due to

[1] Types are defined by a combination of productivity and behavioural parameters. Below we restrict attention to just two type models and only one type parameter distinguishing between firms.

the deadweight loss of taxation (Campbell and Bond, 1997). The output payment includes as special cases where the same price for conservation outputs is paid to both types, and price discrimination.

The farmer's objective function in general is

$$J_{ii} = EU(\sum_t \delta^t \left( p_{ti}\tilde{y}_{ti} + f_{ti} - (c_e(\theta_i^e e_{ti}) + c_x(\theta_i^x, x_{ti}) - \eta(\hat{e}_{ti}, \hat{\mathrm{x}}_{ti}, e_{ti}, \mathrm{x}_{ti}) \right) \tag{4}$$

The utility of the farmer when they truthfully reveal their type is indicated by the subscripts *ii*. The farmer's expected utility when selecting from the menu of voluntary contracts a contract intended for another type is ij. That is the farmer maximizes expected utility, that allows for risk preferences and the function $\eta(\hat{e}_i, \hat{\mathrm{x}}_i, e_i, \mathrm{x}_i)$ indicates the fine payable when effort and land are supplied below the contracted levels $\hat{e}_{ti}$, $\hat{\mathrm{x}}_{ti}$. The ecosystem output may be stochastic $\tilde{y}_{ti}$ in some settings. The participation constraint is that the expected utility from participating is:

$$J_{ii} \geq \bar{J}_i \tag{5}$$

where $\bar{J}_i$ is the farm's reservation expected utility. The incentive compatibility constraint is:

$$J_{ii} \geq J_{ij} \qquad \forall i, j \tag{6}$$

The first subscript is the farm's actual type, which may be defined by multiple type parameters, whilst the second subscript is the farm's declared type. The general contracting problem where the regulator acts as a Stackelberg leader (Baron, 1985) indicates the range of options that the regulator must assess. In its general form, finding an optimal solution to the problem defined by (4), (5) and (6) is analytically intractable, but a subset of more restricted problems do provide insights about the choice of instruments. In the analysis we start with a simple model and develop a set of results for aspects of the general model. If we address one issue of asymmetric information and mechanism design it is not straightforward to jointly address another (Anthon et al, 2010) . For instance, models to address adverse selection may be difficult to generalise to moral hazard or risk aversion without recourse to highly restrictive assumptions. It is a recognised problem of contract theory that complete contract solutions only exist for a subset of contracting problems (Tirole, 1999; Bolton and Dewatripont, 2005).

### 3.3 First-best input and output-based contracts

*Assumptions A1. The regulator observes the producer types, and the productivity of effort (labour) is identical across the two farm types. Farm types are either high land productivity or low land productivity types, with* $\theta_h > \theta_l$. *The regulator maximizes the social-welfare function, and is risk neutral. They can also estimate,* $v, \phi_i$, *and the ecosystem production function:* $\mathrm{y}_{it} = g(x_{ti}, e_{ti}, \mathrm{y}_{it-1})$. *The effort productivity is the same for both types* $\theta^e$.

If the regulator contracts directly on the effort and land supplied for the production of ecosystem services, they maximize:

$$\underset{x_i, e_i, f_i}{Maximum} \left\{ vg(x_i, e_i, \mathrm{y}_{i0}) - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \right\} \text{-} \lambda f_i \qquad i \in l, h \tag{7}$$

(in this section we drop the time subscript), subject to the participation constraint:

$$f_i - (c_e(\theta^e, e_i) + c_x(\theta_i^x, x_i)) \geq 0 \quad i \in l, h \tag{8}$$

The optimal internal solution is:

$$vg_{e_i} = (1+\lambda)c_e^{'}(\theta^e, e_i); \qquad vg_{x_i} = (1+\lambda)c_x^{'}(\theta_i^x, x_i); \qquad i \in l, h \tag{9}$$

The effect of the shadow price of public funds is to increase the marginal cost of the conservation good by the shadow price, which reduces the optimal level of the conservation good. The first best policy is also least cost as (9) implies the condition for cost minimization:

$$\frac{g_{e_i}}{g_{x_i}} = \frac{c_e^{'}(\theta^e, e_i)}{c_x^{'}(\theta_i^x, x_i)} \qquad i \in l, h \tag{10}$$

If instead the regulator contacts on output $y_i$ the firm, as the residual claimant, produces the contracted output at a minimum cost. Define a cost function as:

$$c_y(\theta_i, y_i) = \underset{z \geq 0}{Minimum}[c_e(\theta_i^e, e_i) + c_x(\theta_i^x, x_i) : z_i \in V(y_i);] \quad i \in l, h \tag{11}$$

where $z$ is a vector of inputs in the conservation good and $V(y_i) = \{z_i : g(z_i, y_{0i}) \geq y_i\}$ is a convex input requirement set for the conservation good and $\theta_i = [\theta_i^e, \theta_i^x]$. The modified objective function for the regulator is:

$$\underset{y_i, f_i}{Maximum}\left\{vy_i - c_y(\theta_i, y_i)\right\} \text{-} \lambda f_i \qquad i \in l, h \tag{12}$$

and the participation constraints:

$$f_i - c_y(\theta_i, y_i) \geq 0 \qquad i \in l, h$$

The shadow price of public funds $\lambda$ increases the effective marginal cost of the conservation good and the optimal level of output and input allocated to conservation falls. The input-based and outcome-based contracts are identical as the cost function implies cost minimization.

$$v = (1+\lambda)c_y^{'}(\theta_i, y_i) \tag{13}$$

The input-based contract is also cost minimizing as (10) implies a cost minimizing solution.

***Result 1.*** *The first best input and output contract are equivalent and lead to the same output of the ecosystem service and the same input mix. As the residual claimant, the firm minimizes costs to supply the output specified in the contract. The regulator has the same objective when they determine inputs for an input-based contract. In an input-based contract the regulator benefits directly from cost minimization as it reduces the transfer payment.*

The first-best contracts are illustrated in Figure 2. The regulator would offer the low-cost type of farm the contract at *a* as either an input-based or an outcome-based contract, and the high-cost type the contract at *b*. For an input contract the regulator, as the residual claimant, sets the contracted levels of effort and land so that they minimize the cost of transfer payment related to a level of output and maximize the social welfare function. For the output contract the farms, as residual claimants, would select the cost minimizing input use to maximize their profit.

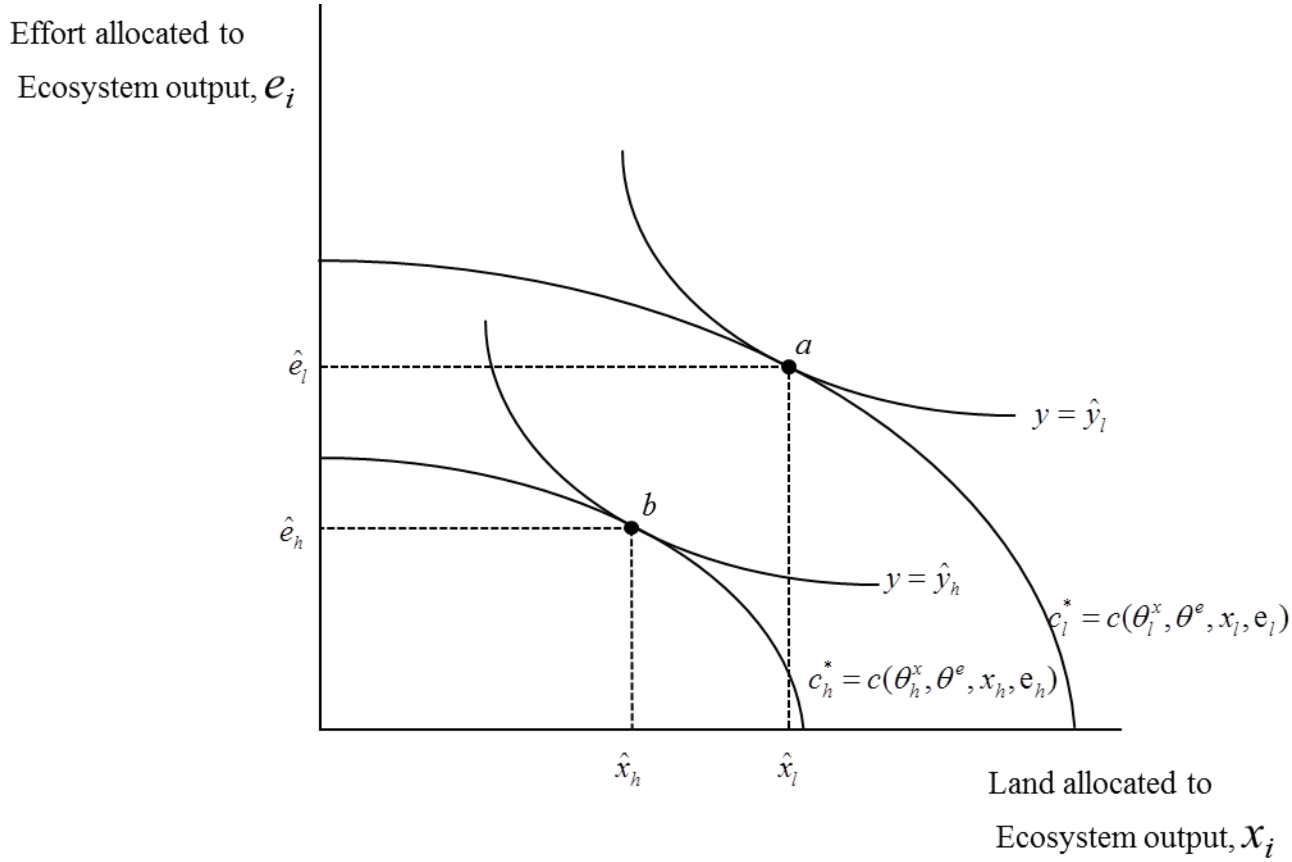



**Figure 2 First-best input-based and outcome-based contracts**

## 3.4 Adverse selection with an input-based contract

*Assumptions A2. The regulator does not observe the land productivity parameterdirectly, but has a subjective estimate of the probability* $\phi_i$ *of the farm's type. The effort productivity is the same for both types.*

The objective function is modified to give the expected social welfare function:

$$\underset{x_i, e_i, f_i}{Maximum} \sum_i \phi_i \left\{ vg(x_i, e_i, y_{0i}) - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \text{-} \lambda f_i \right\} \quad i \in l, h \tag{14}$$

where $\phi_i$ is the probability of a producer being of type i. Thus the objective function (147) is maximised subject to the participation constraints (8) and incentive compatibility constraints:

$$f_i - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \geq f_j - c_e(\theta^e, e_j) - c_x(\theta_i^x, x_j)\text{-} \qquad i, j = l, h;\ i \neq j \tag{15}$$

The assumptions of strictly convex cost functions and the single-crossing property of the incentive compatibility constraint ensures that the participation constraint for the high cost type and incentive compatibility constraint for the low cost type are the only constraints which are binding (see Appendix 1). On this basis the optimal internal solution gives two first-order conditions, the first for the low-cost type:

$$vg_{e_l} = (1+\lambda)c_e^{'}(\theta^e, e_l); \qquad vg_{x_l} = (1+\lambda)c_x^{'}(\theta_l^x, x_l); \tag{16}$$

(thus the low-cost type is offered the first-best solution) and the second for the high-cost type:

$$vg_{e_h} = (1+\lambda)c_e^{'}(\theta^e, e_h); \;\; vg_{x_h} = (1+\lambda)c_x^{'}(\theta_h^x, x_h) + \frac{\lambda\phi_l}{\phi_h}(c_x^{'}(\theta_h^x, x_h) - c_x^{'}(\theta_l^x, x_h)); \tag{17}$$

The second term on the right-hand side of the first-order condition for land is positive by assumption and measures the information rents associated with increasing the input requirements in the contract for the high-cost type. This term also means that the input requirement is no longer cost minimizing for the output of the conservation good as:

$$\frac{g_{e_h}}{g_{x_h}} = \frac{c_e^{'}(\theta^e, e_h)}{c_x^{'}(\theta_h^x, x_h) + \frac{\lambda\phi_l}{(1+\lambda)\phi_h}(c_x^{'}(\theta_h^x, x_h) - c_x^{'}(\theta_l^x, x_h))} < \frac{c_e^{'}(\theta^e, e_h)}{c_x^{'}(\theta_h^x, x_h)} \tag{18}$$

That is, the regulator reduces the requirement for land to be used in the supply of ecosystem services. In the case study this is illustrated where the cost function is assumed to be homogeneous in inputs. In this case the cost minimizing ratio of effort to land is constant and the adverse selection problem entails increasing effort and reducing land allocated to ES production in the optimal contract.

## 3.5 Adverse selection with an outcome-based contract

*Assumption A3. The regulator is not able to observe land productivity types directly and contracts on ecosystem output.*

From an output contract perspective, the problem is re-stated as follows:

$$\underset{y_i, f_i}{Maximum} \sum_i \phi_i \left\{ vy_i - c_y(\theta_i, y_i) \text{-} \lambda f_i \right\} \qquad i \in l, h \tag{19}$$

Subject to the participation constraint:

$$f_i - c_y(\theta_i, y_i) \geq 0 \qquad i \in l, h$$

and incentive compatibility constraints:

$$f_i - c_y(\theta_i, y_i) \geq f_j - c_y(\theta_i, y_j) \qquad i, j = l, h;\ i \neq j \tag{20}$$

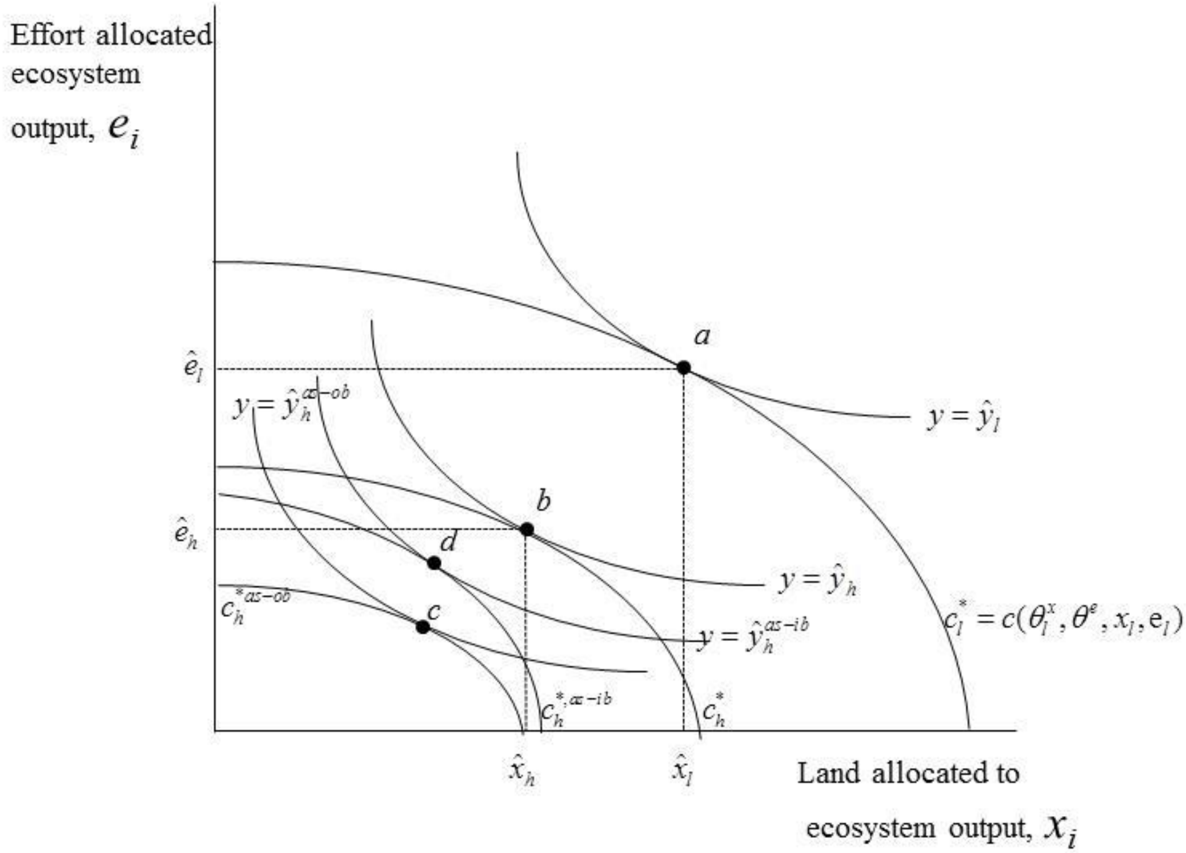
The first order condition for the low-cost farmer is:

$$v = (1+\lambda)c_y^{'}(\theta_l, y_l) \tag{21}$$

For the high cost farmer the output is reduced from compared to the first-best:

$$v = (1+\lambda)c_y^{'}(\theta_h, y_h) + \frac{\lambda\phi_l}{\phi_h}(c_y^{'}(\theta_h, y_h) - c_y^{'}(\theta_l, y_h)); \tag{22}$$

The first-order condition above establishes a point of difference between input-based and outcome-based contracts. Condition (22) indicates a reduction in the ecosystem output compared to the first-best, but, as the farm is the residual claimant for any cost reductions, a profit maximizing farmer produces the contracted ecosystem output at a minimum cost (one of the claimed advantages of outcome-based contracts noted in the introduction). This contrasts with (17) where the inputs are fixed in the menu of contracts by the regulator and the high-cost type can be induced to select an input combination which has a higher proportion of effort than the cost minimizing solution.




*Note: 1.* $y = \hat{y}_h^{as-ib}$ *indicates the isoquant for the adverse selection problem input-based (ib) 2.* $y = \hat{y}_h^{as-ob}$ *indicated outcome-based (ob).3. The isocost curve* $c_h^{*,as-ib}$ *is for adverse selection input-based and includes the informational rent. 4. The isocost* $c_h^{*,as-ob}$ *is for the outcome-based contract.*

**Figure 3 Second-best input-based and outcome-based**

The solution for the high-cost type is given in Figure 3. The contract represented by *b* is the first-best, c is the outcome-based contract and *d* is the input-based contract. The input-based contract is optimal. The outcome-based contract is suboptimal because it constrains the solution to be at the cost minimizing combination of inputs, and whilst this minimizes the costs of producing the conservation good it is not the least cost solution due to the costs of information rent.

***Result 2.*** *With adverse selection, an input contract is weakly preferred by the regulator to an output contract. This result is equivalent to Khalil and Lawaree* (1995) *for a single input model.*

### 3.6 Adverse selection with a mixed contract

If the regulator offers a contract which both sets the land area to be used in ES production but also offers to pay for ecosystem outputs, the following problem is solved

$$\underset{x_i, y_i, f_i}{Maximum} \sum_i \phi_i \left\{ vg(x_i, e_i, \mathrm{y}_{0i}) - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \text{-} \lambda f_\mathrm{i} \right\} \;\; i \in l, h \tag{23}$$

The objective function (23) is maximised subject to the participation constraints (8) and incentive compatibility constraints:

$$f_i - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \geq f_j - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \qquad i, j = l, h; \; i \neq j \tag{24}$$

The optimal internal solution gives two first-order conditions, the first for the low-cost type:

$$vg_{x_l} = (1+\lambda) c_x^{'}(\theta_l^x, x_l); \tag{25}$$

and the second for the high cost type:

$$vg_{x_h} = (1+\lambda) c_x^{'}(\theta_h^x, x_h) + \frac{\lambda \phi_\mathrm{l}}{\phi_\mathrm{h}} (c_x^{'}(\theta_h^x, x_h) - c_x^{'}(\theta_l^x, x_h)); \tag{26}$$

In addition the output constraint is:

$$y_i = g(x_i, e_i, \mathrm{y}_{0i}) \tag{27}$$

Note that there are no explicit conditions on effort, as effort is not specified in the contract, only land. By contracting on land and ecosystem outputs, the regulator induces the producer to select the level of effort that maximises (23). This is:

$$e_i = \mathrm{argmin}[c_e(\theta^e, e_i); \hat{y}_i = g(\hat{x}_i, e_i, \mathrm{y}_{0i}), x_i = \hat{x}_i] \tag{28}$$

Thus, with just two inputs, the optimal level of effort is directly determined by the regulator.

***Result 3.*** *A mixed contract on output and land is equivalent to the optimal input-based solution to the adverse selection problem.*

### 3.7 Adverse selection where the type relates to an unobservable variable

*Assumption A4. The land productivity type is commonknowledge, but effort productivity is not. The regulator can contract on land and output.*

In this model set-up the unobserved type relates to effort productivity $\theta_i^e$ while the land productivity is observed. The regulator's objective function is:

$$\underset{x_i, f_i}{Maximum}\sum_i \phi_i \left\{vg(x_i, e_i, \mathrm{y}_{0i}) - c_e(\theta_i^e, e_i) - c_x(\theta_i^x, x_i) \text{-} \lambda f_\mathrm{i}\right\} \quad i \in l, h \qquad (29)$$

This is an adaptation of (14) where the productivity of effort is different for the two types, but the land productivity is known. Neither effort nor effort productivity are directly observed. A fully-specified input contract is infeasible, but if land and output are contractable, a separating contract may be feasible. Consider the incentive constraint:

$$\widehat{e}_i = \mathrm{argmin}[(c_e(\theta_i^e, e_i) + c_x(\theta_i^x, x_i)); \mathrm{y}_i = \mathrm{g}(e_i, x_i, \mathrm{y}_{0i})] \quad i \in l, h$$

The optimal level of effort is given as a function of the productivities, the amount of contracted land and output:

$$\widehat{e}(\theta_i^e, \theta_i^x, \hat{x}_i, \hat{\mathrm{y}}_i) \quad i \in l, h$$

The corresponding incentive compatibility constraint is:

$$f_i - c_e(\theta_i^e, \widehat{e}_i) - c_x(\theta_i^x, x_i) \geq f_j - c_e(\theta_i^e, \widehat{e}_j) - c_x(\theta_i^x, x_j) \qquad i, j = l, h;\ i \neq j$$

The internal solution is where:

$$vg_{e_l} = (1+\lambda)c_e^{'}(\theta_l^e, \widehat{e}_l);\ v(g_{x_l} + \hat{e}_{x_l} g_{e_l}) = (1+\lambda)(c_x^{'}(\theta_l, x_l) + c_e^{'}(\theta_l^e, \widehat{e}_l)\hat{e}_{x_l}); \qquad (30)$$

And for the high cost type:

$$vg_{e_h} = (1+\lambda)c_e^{'}(\theta_h^e, \widehat{e}_h) + \frac{\lambda\phi_l}{\phi_h}(c_e^{'}(\theta_l^e, \widehat{e}(\theta_l^e, \theta_l^x, x_h, \mathrm{y}_h))\text{-}c_e^{'}(\theta_l^e, \widehat{e}(\theta_l^e, \theta_l^x, x_l, \mathrm{y}_l));$$

$$v(g_{x_l} + \widehat{e}_{x_l} g_{e_l}) = (1+\lambda)(c_x^{'}(\theta_l^x, x_l) + c_e^{'}(\theta_l^e, \widehat{e})\widehat{e}_{x_l};$$

The land area has both a direct effect on the supply of ecosystem services through the ecosystem production function and an indirect effect by changing the optimal effort. Both the effort and land area used to produce the ecosystem output are less than the first best.

**Result 4.** *If hidden information relates to the producitivity of an unobservable input it is possible to design an efficient contract through a contract on the observable input and output.*

## 3.8 Moral hazard

*Assumption A5 the regulator contracts on both effort and land. Land is costly to monitor, and effort also requires costly monitoring.*

If a contracted input is unobservable without the regulator engaging in active monitoring then the contract is prone to moral hazard, as the farm may shirk on the contracted level of effort. Within the model developed here, two approaches emerge for dealing with moral hazard; either direct monitoring and penalties, or mixed contracts where the contract specifies costly-to-fake variables such as output and land use. These are sufficient to ensure an optimal level of use of the unobservable variable. If, for instance, output is costly to measure, then the regulator may have to monitor effort directly and use an input-based contract.

The effectiveness of monitoring depends on the capacity of the regulator to charge a fine for applying less effort than contracted (White, 2002). Monitoring frequency lies in a range $0 \leq m \leq 1$ and has a cost $c^m$ of full monitoring. The fine per unit of effort undersupplied (relative to the contracted level of effort) is $\eta$. The result for the input contract is that:

$$vg_{e_i} = (1+\lambda)c_e^{'}(e_i) + \frac{c_m}{\eta} c_e^{''}(e_i); \quad i \in l, h$$

**Result 5.** *The regulator monitoring contract is less efficient than either the input-based or mixed contract, as the second term on the right-hand side reduces effort. This result indicates that if ES output can be observed at a relatively low cost, the mixed contract is an alternative to contracting on effort and engaging in costly monitoring.*

## 3.9 Price contracts

*Assumption A6. The regulator contracts using a fixed price on output, but does not specify the quantity of output.*

In the last section adverse selection was addressed through differentiated contracts on either outputs or inputs. An alternative approach is to establish an undifferentiated price for the output and allow producers to self-select both the inputs and ES outputs. This form of contracts is defined as follows:

$$\underset{p}{Maximum}\sum_i \phi_i \left\{ v\mathrm{y}_\mathrm{i} - c_y(\theta_i, y_i)\text{-}\lambda p\mathrm{y}_\mathrm{i} \right\} \;\; i \in l,h \tag{31}$$

Here the objective function is changed relative to (14) so that the total public expenditure for each farmer is $p\mathrm{y}_\mathrm{i}$ rather than a fixed transfer payment $f_\mathrm{i}$. The constraints on the problem are as follows:

$$p\mathrm{y}_\mathrm{i} - c_y(\theta_i, y_i) \geq 0 \qquad i \in l,h$$

In this case the participation constraint ensures that both farms have an incentive to participate at the fixed output price. The second condition is that the output level must statisfy:

$$y_i = \mathrm{argmax}[py_i - c_y(\theta_i, y_i)]$$

Assuming differentiability, each firm selects output such that:

$$p - c_y^{'}(\theta_i, y_i) = 0 \quad\; i \in l,h \tag{32}$$

If this is substituted into (31) for price the first order condition for the optimal output and therefore the optimal price is determined by satisfying:

$$v = (1+\lambda)\{\phi_l c_y^{'}(\theta_l, y_l) + \phi_h c_y^{'}(\theta_h, y_h)\} + \lambda\{\phi_l y_l c_y^{''}(\theta_l, y_l) + \phi_h y_h c_y^{''}(\theta_h, y_h)\} \; i \in l,h \tag{33}$$

The first term on the right-hand side can be interpreted as the average marginal cost, the second term is the average of $y_i c_y^{''}(\theta_i, y_i)$. Equation (33) can be rewritten by noting that for a price scheme $p = c_y^{'}(\theta_l, y_l) = c_y^{'}(\theta_h, y_h)$:

$$\mathrm{v}=(1+\lambda)\{c_y^{'}(\theta_i, y_i)\}+\lambda\{\phi_l y_l c_y^{''}(\theta_l, y_l)+\phi_h y_h c_y^{''}(\theta_h, y_h)\} \qquad (34)$$

Thus for a price contract the low cost producer reduces supply relative to the first best solution (13)as the second term on the right-hand side is positive. The output supplied is reduced for both types relative to the adverse selection problem and both producers receive a rent equivalent to a producer surplus.

*Assumption A7. The regulator specifies a menu of ecosystem output prices and a land allocation.*

A feasible separating price discriminating solution may also be available if a land area and price are specified for each producer type. The low cost farm is expected to allocate a larger area of land to ES provision than the high cost farm. The results are given in Appendix 2. The objective function is:

$$\underset{x_i, \mathrm{p_i}}{Maximum} \sum_i \phi_i \left\{ vg(x_i, e_i, \mathrm{y}_{0i}) - c_e(\theta_i^e, e_i) - c_x(\theta_i^x, x_i) \text{-} \lambda p_i g(x_i, e_i, \mathrm{y}_{0i}) \right\} \;\; i \in l, h \qquad (35)$$

Subject to $\quad e_i = \mathrm{argmax}[(\mathrm{p}_i \mathrm{g}(e_i, x_i, \mathrm{y}_{0i}) - c_e(\theta_i^e, e_i) - c_x(\theta_i^x, x_i))] \quad i \in l, h$

And the *IC-l* constraint:

$$p_l y_l - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \geq p_h y_l(p_h, x_h) - c_e(\theta^e, e_h) - c_x(\theta_l^x, x_h)$$

The term $y_l(p_h, x_h)$ gives the response of the low cost type to the price and the area of the high cost type. It is equivalent to a menu auction (Bichler and Kalagnanam, 2003) where the regulator specifies a menu of land inputs and the price determined can be viewed as an (undisclosed) reserve price above which bids are rejected.

***Result 6.*** *Fixed price contracts are relatively costly to the regulator as they pay more rent than the first-best contract. However, there is the potential for the regulator to price discriminate by contracting on land and setting different prices for the producer types.*

### 3.10 Risk-averse farmers

In this section and the next on dynamics the regulator is assumed to able to observe the farm type. This assumption is to simplify the analysis. Separating contracts that provide the basis for a menu of contracts that increase the efficiency of agri-environmental schemes may be feasible so long as farmers objective function still exhibit the single-crossing property (Laffont and Tirole, 1993).

*Assumption A7. In this section the regulator observes farm type. The ecosystem output is stochastic and the regulator can contract directly on land, but not output or effort. Farmers are risk averse and have a CARA expected utility function. (Bolton and Dewatripont, 2005, p142). Farm types are common knowledge*

One critique of outcome-based contracts is that if output is stochastic they reduce participation amongst risk averse farmers. We analyse contracting with risk averse farms in two ways. First we consider a CARA mean-variance formulation and show that potentially risk aversion could reduce the efficiency of agri-environmental schemes. An alternative solution suggested initially by Mirlees in 1975 (published in 1999) is that the regulator specifies a minimum ecosystem output standard, a land area and a fine for underprovision of output and is able to approximately achieve the first-best solution.

Initially we assume that farmers are risk averse. The stochastic ecosystem output is given by:

$$\tilde{y}_i = \bar{g}(e_i, x_i, \mathrm{y}_{0i}) + \tilde{\varepsilon}_i \tag{36}$$

With a stochastic output a risk neutral regulator would select inputs or output to maximize:

$$\underset{x_i, e_i, f_i, p_i}{Maximum}\left\{v\bar{g}(x_i, e_i, \mathrm{y}_{i0}) - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i)\right\} \text{-} \lambda( f_i + \mathrm{p}_i \bar{g}(x_i, e_i, \mathrm{y}_{i0})) \qquad i \in l, h$$

such that:

$$\frac{\bar{g}_{e_i}}{\bar{g}_{x_i}} = \frac{c_e^{'}(\theta^e, e_i)}{c_x^{'}(\theta_i^x, x_i)} \qquad i \in l, h$$

and

$$v\bar{g}_{e_i} = (1+\lambda)c_e^{'}(\theta^e, e_i); \qquad v\bar{g}_{x_i} = (1+\lambda)c_x^{'}(\theta_i^x, x_i); \qquad i \in l, h$$

These are the stochastic equivalent of (9).

Random ecosystem service output shocks $\tilde{\varepsilon}$ are normally distributed with mean zero and variance $\sigma^2$. The firm's stochastic profit is given by:

$$\tilde{\pi}_i = \{ f_i + p_i\bar{g}(e_i, x_i, \mathrm{y}_{0i}) - (c_e(\theta^e, e_i) + c_x(\theta_i^x, x_i))\} + p_i\tilde{\varepsilon}_i \tag{37}$$

where $f_i$ is a lump-sum transfer payment and $p_i$ an output based payment. The firms' expected utility is given by:

$$U(\tilde{\pi}_i) = f_i + p_i\bar{g}(e_i, x_i, \mathrm{y}_{0i}) - (c_e(\theta^e, e_i) + c_x(\theta_i^x, x_i)) - r(p_i\sigma)^2 \tag{38}$$

In this setting (Martimort and Sand-Zantman, 2006) the term in braces in (37) gives the expected income where $\bar{g}(e_i, x_i, \mathrm{y}_{0i})$ is defined as the expected output and the transfer is given per unit of output. The firms absolute risk aversion is *r* and $\sigma$ gives the standard deviation of output. The risk neutral regulator maximizes:

$$\underset{x_i, f_i, p_i}{Maximum}\left\{v\bar{g}(x_i, e_i, \mathrm{y}_{0i}) - c_e(\theta^e, e_i) - c_x(\theta_i^x, x_i) \text{-} \lambda( f_{\mathrm{i}} + p_i\bar{g}(x_i, e_i, \mathrm{y}_{0i}))\right\}$$

Subject to a participation constraint based on (38) and an incentive compatibility constraint to determine the level of effort:

$$e_i = \mathrm{argmax}[ f_i + p_i\bar{g}(e_i, x_i, \mathrm{y}_{0i}) - (c_e(\theta^e, e_i) + c_x(\theta_i^x, x_i)) - r(p_i\sigma)^2] \tag{39}$$

this can be solved as a first derivative constraint on the effort:

$$p_i\bar{g}_{e_i} - c_e^{'}(\theta^e, e_i) = 0$$

It is worth noting that the effort only affects the mean ecosystem output and the deterministic cost of effort. A generalisation could allow the effort to determine the variance.

The alternative to addressing risk aversion directly is to require that the farmer provides a minimum level of output (Mirlees, 1999) and apply severe penalties if this output level is not achieved. This would provide a risk averse farmer with an incentive to increase land and effort allocated to ES supply to a point where the probability of incurring the penalty were reduced to close to zero. This would apply as follows. The minimum output specified in the contract is $y_i^m$. If the regulator sets up a contract with a punitive fine if the output is less than $y_i^m$, the participating firm has the expected ulility:

$$\underset{e_i}{Maximum}\left\{\tau(e_i,y_i^m)U((f_{\mathrm{i}}-c_e(\theta^e,e_i)-c_x(\theta_i^x,x_i))+(1-\tau(e_i,y_i^m))\,\mathrm{U}(-\Gamma-c_e(\theta^e,e_i)-c_x(\theta_i^x,x_i))\right\}$$

Here $\Gamma$ is a fixed fine applied when output is less than the minimum output and $\tau(e_i)$ is the probability that output exceeds, $y_i^m$. In this contract setting the regulator can approximately achieve the first-best solution by making the fine large and $y_i^m$ sufficiently stringent. For instance as $\tau(e_i,y_i^m)$ approaches zero, utility is maximized by selecting the least cost combination of inputs, the contracted land area plus the minimum output constraint, then this should be sufficient to induce effort that ensures on average the optimal ecosystem output is achieved.

**Results 7.** *If the regulator cannot contract directly on stochastic output and has to rely on an output payment combined with a fixed payment to incentivise effort and thus output, then risk aversion is detrimental to the performance of agri-environment schemes. If instead the regulator can contract on a minimum level of output and impose a stringent penalty, it may be possible to approximately achieve the first-best solution.*

## 3.11 Recontracting and dynamics

*Assumption A8. This section assumes perfect information relating to firm type to explore two-period dynamic contracting.*

The provision of ecosystem services through time is an investment problem that can be characterised as follows. Land and effort combine is a production process to increase the stock of capital $y_t$.The capital formation function should allow for depreciation as well as growth, and ecosystem capital has an upper bound where the ecosystem reaches a steady state.

In a dynamic setting separating contracts may not be incentive compatible if the regulator is expected to use the information to “ratchet-up” the efficiency required on the basis of the information on type revealed by the farm (MacKenzie et al, 2008). Contracts should also be renegotiation proof. The result is that simpler pooling or price-based contracts may be a feasible alternative to a menu of contract.

For two contracting periods the regulator maximizes:

$$\underset{y_{ti},x_i,e_i,f_i}{Maximum} \sum_{t=1,2} \delta^{t-1} \left\{ v y_{ti} - c_e(\theta^e e_{ti}) - c_x(\theta_i^x, x_{ti}) \right\} \tag{40}$$

The first best solution is subject to a dynamic participation constraint:

$$f_{1i} - c_e(\theta^e, e_{1i}) - c_x(\theta_i^x, x_{1i}) + \delta^t (f_{2i} - c_e(\theta^e, e_{2i}) - c_x(\theta_i^x, x_{2i})) \geq 0 \qquad i = l, h \tag{41}$$

The transfers are substitutable and the regulator may prefer to delay payments until the second period. If the payment is output-based and the output is uncertain, the regulator may consider a scheme such as that represented by (38) where payment includes a fixed payment and an output based payment.

In terms of the design of this form of contract, the key policy parameter is the contract duration: if a farmer is offered a relatively long contract they discount transfer payments, expect higher costs and may also expect higher variability in the output variable (Broch and Vedel, 2011).

An issue arises when a habitat reaches an equilibrium steady state where no further increase in the ecosystem asset are possible. Maintenance effort would have to be paid for directly possibly coupled with penalties for ecosystem degradation. In this case, paying for increases in the ecosystem asset or output are not effective.

*Results 8. Dynamic contracting is an area where straightforward results are difficult to establish. From the provisional analysis here, there is considerable flexibility in how contacts are managed over extended contracting periods. The following should be included in most schemes. (i) Outcome monitoring that allows for a contract to be terminated early; (ii) Some flexibility to allow farms to "catch-up" by increasing effort if the ecosystem asset is below the required level; (iii) Contract durations that are long enough to allow for ecological change to be observed, but short enough so that discounting combined with risk aversion do not* *undermine the incentive to manage the ecosystem; (iv) A policy should include a long term protection scheme that prevents farms from responding to perverse incentive to degrade valuable ecosystem assets when the ecosystem is close to a steady state and increases in output are small. If these are included in the original contract – contingent upon a satisfactory output being achieved over the initial contracting period - this should provide farmers with a strong incentive to put effort into conservation.*

# 4 A case study

The south-west corner of Western Australia is designated by Conservation International as a Biodiversity Hotspot (Myers et al., 2000). This designation indicates a region of high endemic plant biodiversity, and yet it is under a high level of threat from agriculture. For instance, NEWROC (Northeast Wheatbelt Regional Organisation of Councils) region has around 12% of its indigenous vegetation remaining. The role of input and output based agri-environmental schemes and the characteristics of the study region are described by White and Sadler (2012).

The remaining biodiversity in the region is found in remnant woodland, shrub and mallee heath, collectively termed "bush remnants". The threats to biodiversity include land clearing for cereal and sheep production (although further clearing is banned), the encroachment of agricultural weeds and sheep grazing. Management practices include excluding sheep through fencing, weeding and replanting. The regulator (the Western Australian Department of Parks and Wildlife) can identify the area of land that is fenced and included in a conservation scheme cheaply. Conservation efforts by the farmer are almost impossible to observe and record in a way that is legally enforceable. Similarly the management of sheep grazing is difficult to observe whilst the value of the bush remnants for grazing depends on the farming system. The opportunity cost of the labour element of conservation effort is also difficult to observe and highly variable (White and Sadler, 2012). This is a region where land sparing rather than land sharing (Balmford et al, 2012) is the best strategy as the ecosystem benefits are close to zero on land planted to crops or used for intensive grazing.

The nature of the ecosystem services provided by remnant bush is complex. It includes storing biodiversity, sequesting carbon and reducing the rate of dryland salinity spread. The social value of these components is likely to be context specific and highly variable. Non-market valuation of biodiversity protection for Western Australia have indicated high values and shows that the Western Australian population has some awareness of the diversity of flowering plants in such areas (Burton et al., 2012)

Conservation outcome measurement is feasible and reasonably inexpensive if it is undertaken by remote sensing either through aerial photographs or satellite data. In contrast, field surveys of ecological condition given the remoteness of the region are expensive. As the authors show a bush condition metric (crudely a measure of tree and understorey) is highly variable. This is partly due to the Western Australian climate which is prone to frequent droughts and fires. Therefore risk aversion is potentially an issue for an outcome-based scheme. The farms are large with an average size of farms surveyed 6593ha with a high level of capital investment and low level of labour. Despite their large size, most farms employ only one person and can be categorized as family farms.

Here, the duration of agri-environmental contracts is important. Any change in the bush management would probably take about three years to take effect, with a significant change after six to ten years (Prober and Smith, 2009). There is a distinct possibility that the bush could deteriorate if there is sub-optimal effort.

## 4.1 Results for deterministic contracts

Table 1 shows parameter values and functional forms for the expressions in the theoretical model. The results in Table 2 show that where there is perfect information the regulator can achieve the same level of efficiency with an input contract (contract 1) and an output contract, contract 3. In the case of hidden land productivity, an input contract (contract 2) is slightly more efficient than an output contract (contract 4). Mixed contracts (contract 5) which target land and output are as efficient at addressing adverse selection as an input contract and can also induce a farmer to supply an optimal level of effort. This is an interesting result that holds trivially for the case of two inputs but in more complex policy settings may suggest that regulators should consider targeting more observable variables that then give an indirect incentive to provide inputs that are unobservable.

**Table 2 here**

Simple price contracts (contract 6) and price discriminating contracts (contract 7) are less efficient than contracts 1 through to 5, but this is due to the deadweight loss of taxation and the emergence of a producer surplus. Price discrimination, where the price of the low cost type is lower than and the land area contracted is higher than that for the high cost type reduces the producer rent, but not by much in this example. These two contracts raise an interesting issue about whether in the long term is it better to allow farmers to profit from providing ecosystem services much in the same way as they profit from providing market goods. Note also that a pricing approach would place an emphasis upon the ability to estimate the non-market and market values of ecosystems assets.

### 4.2 Risk aversion

If farmers are risk averse and the regulator can contract on land but not output or effort then the results change markedly. Results for the low cost type are given in Table 3 for a range of values of the absolute risk aversion coefficient. They show that, as risk aversion increases, the output based payment falls and the fixed payment increases. The value of the regulator's objective function falls as the rent paid to more risk averse producers increases. This solution implies that regulators may avoid contracting with highly risk averse farmers. Risk neutral farmers are prepared to accept high-powered incentive schemes where they are the residual claimant of their own efforts, due to the greater weight on output based price component. High-powered incentives are less attractive to highly risk averse farmers as it increases the weight on the variance and thus the cost of risk.

**Table 3 here**

The Mirlees approach to designing contracts with risk averse farms would require a fixed fine $\Gamma$ for a level of ecosystem output below a target $y_i^m$, and a contracted land area $\hat{x}_i$ that could be set at the first best. With this contract setting the farm could be induced to apply the optimal effort. For instance for the low cost type, if the fine is set at \$100000 and the output target is $y_i^m = 24.87$, this would induce a first-best level of effort. The probability of the firm not achieving the output target is: 0.01.

## 5 Conclusions

This paper reviews a range of policy designs depending upon the assumptions made about information, preferences and dynamics. The benefits of understanding the ecosystem service outputs and how they relate to inputs are significant. Schemes are often established without this fundamental information in place. Notably in their assessment of European agri-environmental policy the European Court of Auditors (2011) conclude: "*The Court found that the objectives determined by the Member States are numerous and not specific enough for assessing whether or not they have been achieved. … In particular, very little information was available on the environmental benefits of agri-environment payments.* (European Court of Auditors, 2011, p7).

The aim of policy design is to target costly-to-fake variables that you can provide an incentive for farmers to apply management and labour inputs to the provision of public ecosystem assets. This paper identified a series of results that offer insights into policy design. Result 1 is that with perfect information about farm type, the regulator is indifferent between offering an input-based or output-based contract. Result 2 extends a result by Khalil and Lawaree (1995) to the case where there are two inputs (one observable by the regulator and the other not) and shows that there is an efficiency gain from using input-based contracts to address adverse selection. This result hinges on the ability of the regulator to minimize the informational rent by adjusting the effort to land ratio away from the cost minimizing solution. Result 3 shows that if the regulator is able to measure output and contract on it then they can provide an incentive for an optimal level of the unobservable effort and informational rent. Result 4 shows that even if the productivity type relates to the unobservable input effort it is possible to derive separating solutions. Result 5 shows that contracting on output eliminates the requirement for explicit effort monitoring.

A price-based contract that pays on output is attractive in terms of its administrative requirement as it only requires output monitoring. However, Result 6 shows that fixed price contracts are relatively costly to the regulator as they pay more rent to farmers (Hanley et al, 2012). However, there is the potential for the regulator to price discriminate by contracting on land and setting different prices for the producer types, and this reduces the rent they earn and thus improves cost-effectiveness (Armsworth et al, 2012).

Result 7 shows that if the regulator cannot contract directly on stochastic output and has to rely on an output payment combined with a fixed payment to incentivise effort and thus output, then risk aversion is detrimental to the performance of agri-environmental schemes. If instead, the regulator can contract on a minimum level of output and impose a stringent penalty it may be possible to approximately achieve the first-best solution.

For the dynamic model, theoretical results are less clear cut.  Issues of renegotiation and adverse selection can be partially addressed by making contract durations consistent with a period over which ecological change occurs.  To overcome discounting and risk aversion it may be necessary to pay in stages.  Once a steady state of the natural asset is reached, then a farmer cannot be rewarded for ecosystem asset accumulation but should be paid an incentive to avoid behaviour that leads to the degradation of the resource through neglect.

These results have been devised by analysis of highly simplified models, combined with a simulation of an actual policy setting.  Clearly there are limitations to this approach and there is a requirement for further research into more complex contracting setting, especially those relating to areas with multiple farm types and repeated contracting.

An interesting result is that measuring and valuing ecosystem outputs is critical to the design of agri-environmental.  First, if outputs are not measured there is no means of measuring the success of a scheme.  If values are not assessed it is hard to know at what level of intensity and scale the ecosystem service should be provided.  Second, measuring output opens up a larger range of contracting options for the regulator especially if ecosystem output or some aspect of ecosystem output can be measure accurately and cheaply.  In the case study this was true with the use of remote sensing data.  This is critical where farmers' effort is unobservable.

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**Appendix 1 Input-based contracts asymmetric information**

The analysis of the theoretical model is greatly simplified by the fact that the IC for the low cost farm and the IR constraint for the high cost farm are the only constraints that are binding. Following Laffont and Tirole (1993,p59). The IC-*l* constraint:

$$f_l - (c_e(\theta^e, e_l) + c_x(\theta_l^x, x_l)) \geq f_h - (c_e(\theta^e, e_h) + c_x(\theta_l^x, x_h)) \qquad \text{(A1)}$$

The *IR-h* constraint $f_h - (c_e(\theta^e, e_h) + c_x(\theta_h^x, x_h)) \geq 0$ implies:

$$f_l - (c_e(\theta^e, e_l) + c_x(\theta_l^x, x_l)) \geq (c_e(\theta^e, e_h) + c_x(\theta_h^x, x_h)) - (c_e(\theta^e, e_h) + c_x(\theta_l^x, x_h)) \geq 0$$

As $f_h$ is at least $(c_e(\theta^e, e_h) + c_x(\theta_h^x, x_h))$, Thus we can ignore the *IR-l* constraint as it is implied by *IC-l.*

If we now optimize (14) with respect to *IC-l* and *IR-h* it is possible to check that *IC-h* is satisfied from the first order conditions (16) and (17), $x_l > x_h$ and $e_l > e_h$.

If we restate the *IC-l* constraint:

$$\begin{aligned} R_l &\geq R_h - ((c_e(\theta^e, e_h) + c_x(\theta_l^x, x_h)) + (c_e(\theta^e, e_h) + c_x(\theta_h^x, x_h)) \\ &\geq R_h - c_x(\theta_l^x, x_h) + c_x(\theta_h^x, x_h) \end{aligned}$$

Where $R_i$ *is the rent.* The *IC-h is:*

$$R_h \geq R_l - ((c_e(\theta^e, e_l) + c_x(\theta_h^x, x_l)) + (c_e(\theta^e, e_l) + c_x(\theta_l^x, x_l)) \geq R_l - c_x(\theta_h^x, x_l) + c_x(\theta_l^x, x_l)$$

Bringing the constraints together:

$$0 \geq (c_x(\theta_h^x, x_h) - c_x(\theta_l^x, x_h)) - c_x(\theta_h^x, x_l) + c_x(\theta_l^x, x_l)$$

This assumptions holds as long as the $c_x'''(\theta_i^x, x_i) \geq 0$.

**Appendix 2 Price discrimination**

The approach to solving this problem is to define the effort as given by: $p_i\, g_{e_i} = c_e^{'}(\theta^e, e_i)$. If this is binding for the low cost type, the price for the high-cost type can be derived from the incentive compatibility constraint. The first order conditions for the area of the high cost farmer are:

$$v = (c_x^{'}(\theta_h^x, x_h) + \lambda c_x(\theta_l^x, x_h)) / g_{x_h}$$

For the low cost type:

$$v = \frac{\lambda p_l\, g_{x_l} - \lambda \phi_h c_x^{'}(\theta_l^x, x_l) + \phi_l c_x^{'}(\theta_l^x, x_l) + \lambda y_l (c_e^{'}(\theta^e, x_l)\, g_{x_l x_l} / g_{x_l}}{\phi_i\, g_{x_l}}$$

**Table 1. Notation used in theoretical and empirical models**

| Symbol | Description | Unit | Value/functional form |
|---|---|---|---|
| *Indices:* | | | |
| $i,j$ | Farm type (land productivity) | - | $i,\ j=[l,h]$ |
| $t$ | Time period | - | $t=[0,1,2]$ |
| *Parameters:* | | | |
| $\theta_i^x$ | Land productivity parameter for farm type *I* measured as crop output. | | $\theta_l^x=2095;\quad \theta_h^x=2\theta_l^x$ |
| $\theta_i^e$ | Effort productivity if farm types have the same productivity this is indicated by dropping the subscript: $\theta^e$ | | $\theta_l^x=32.76;\quad \theta_h^x=2\theta_l^x$ |
| $p^a$ | Agricultural commodity price (for example wheat) | $\$t^{-1}$ | |
| $w^a$ | Agricultural input prices, for instance fertilizer. | $per unit | |
| $\delta^t$ | Discount factor at time *t* | Per cent | $\delta^t=(1/(1+r))^t$ |
| $\phi_i$ | Probability that a firm is of type *i.* | | |
| $v$ | Is the economic value per unit of ecosystem service | $ unit metric | 60.25 |
| $r$ | Coefficient of risk aversion | | *0 to 0.4* |
| $\lambda$ | Shadow cost of tax funds | $\$^{-1}$ | *0.1,* $0\le\lambda\le1$ |
| $\eta$ | Fine for non-compliance on effort. | $ per unit effort | |
| *Variables:* | | | |
| $\overline{x}_i^a$ | Fixed land area available for agriculture and conservation | ha | |
| $\overline{\mathrm{e}}_i^a$ | Fixed effort available for agriculture and conservation | hours | |
| $x_i$ | Land allocated from agriculture to conservation | ha | |
| $\mathrm{e}_i$ | Effort allocated from agriculture to conservation | hours | |
| $\mathrm{y}_{ti}$ | Ecosystem output | metric | |
| $f_{ti}$ | Transfer payment from the regulator to farmer | $ | |
| $\mathrm{p}_{ti}$ | Output payment. | $ per unit of metric | |
| *Functions:* | | | |
| $\pi(\theta_i^x,\theta_i^e,p,w,\overline{x}_i^a,\overline{\mathrm{e}}_i^a)$ | Agricultural profit as a restricted profit function. | $ | |
| $c(\theta_i^x,\theta_i^e,x_i,\mathrm{e}_i)$ | Compliance cost function of providing $\{x_i,\mathrm{e}_i\}$ to conservation | $ | |
| $c_x(\theta_i^x,x_i)$ | Opportunity cost of land | $ | $\theta_i^x(x_i)^{\beta_1}\ \beta_1=1.5;$ |
| $c_e(\theta_i^e,e_i)$ | Opportunity cost of effort | $ | $\theta_i^e(e_i)^{\beta_2};\ \beta_2=1.5;$ 3 |
| $c_y(\theta_i,y_{ti})$ | Minimum cost for firm *i* to produce ecosystem output $\mathrm{y}_{ti}$ | | |
| $\mathrm{y}_{ti}=g(x_{ti},e_{ti},\mathrm{y}_{t-1i})$ | Ecosystem production function, measure of the accumulation of natural capital. | metric | $y_{t+1i}=b_0x_{ti}^{b_1}e_{ti}^{b_1}y_{ti}$ $b_0=1;b_1=0.6;b_2=0.2;$ |
| $\mathrm{c}_m(e_{ti},x_{ti})$ | Is a convex resource cost of monitoring conservation contracts | | |
| $\eta(\hat{e}_{ti},\hat{\mathrm{x}}_{ti},e_{ti},\mathrm{x}_{ti})$ | Expected fine for non-compliance | | |

*Note: Unless otherwise stated parameters taken from White and Sadler, (2012). 1. The land cost is based on the opportunity cost of land for sheep grazing and the cost of maintaining fencing. 2. Estimated from the results of a choice modelling survey Burton et al. (2012, p7). 3. The parameters* $\beta_2,\beta_2$ *are set equal to ensure homogeneity of the cost function in the inputs. This ensures that the effort to land ratio is constant where cost is minimized.*

## Table 2 Agi-environmental contracts

| | J | $e_l$ | $e_h$ | $x_l$ | $x_h$ | $y_l$ | $y_h$ | $f_l$ | $f_h$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Contracts | Social welfare | Effort low-cost | Effort high-cost | Land low-cost | Land high-cost | Output low-cost | Output high-cost | Transfer payment low-cost | Transfer payment high-cost | Rent *l* | Rent *h* |
| Input-based | | | | | | | | | | | |
| 1.First-best | 13636 | 105.67 | 97.82 | 20.16 | 14.24 | 29.87 | 26.61 | 14484 | 12900 | 0 | 0 |
| 2.Mechanism design input | 13556 | 105.67 | 95.71 | 20.16 | 12.91 | 29.87 | 25.75 | 15412 | 12147 | 928 | 0 |
| Output-based | | | | | | | | | | | |
| 3.First-best | 13636 | 105.67 | 97.82 | 20.16 | 14.24 | 29.87 | 26.61 | 14484 | 12900 | 0 | 0 |
| 4.Mechanism Design output | 13553 | 105.67 | 93.74 | 20.16 | 13.65 | 29.87 | 25.71 | 15492 | 12100 | 1008 | 0 |
| 5.Mixed output/land-based | 13556 | 105.67 | 95.71 | 20.16 | 12.91 | 29.87 | 25.75 | 15412 | 12147 | 928 | 0 |
| Price-based | | | | | | | | $p_l$ | $p_h$ | | |
| 6.Single-price contract | 7875 | 28.41 | 26.30 | 5.42 | 3.83 | 10.45 | 9.31 | 363 | 363 | 1769 | 1576 |
| 7.Price discrimination | 12558 | 91.55 | 84.47 | 20.35 | 14.36 | 27.46 | 24.40 | 798 | 795 | 9469 | 8381 |

## Table 3 Risk aversion for low-cost type

| Absolute risk aversion, *r* | J | $x_l$ | $e_l$ | $y_l$ | $f_l$ | $p_l$ | Rent |
|---|---|---|---|---|---|---|---|
| zero | 12839 | 91.82 | 20.34 | 27.51 | 0 | 800 | 9528 |
| 0.1 | 7176 | 39.22 | 16.36 | 15.81 | 29142 | 388 | 30179 |
| 0.2 | 5161 | 24.25 | 13.79 | 11.45 | 27469 | 261 | 27213 |
| 0.3 | 4123 | 17.50 | 12.14 | 9.18 | 24468 | 199 | 23876 |