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# Auctioning contracts for environmental services

Peter Bardsley and Ingrid Burfurd<sup>†</sup>

Policy-based markets for environmental services include government procurement, private procurement to satisfy regulatory requirements and private procurement through government offset markets. These markets are increasingly popular and raise questions about optimal procurement under different regulatory frameworks. The design of these schemes draws together issues in auction design and contract theory. Using a mixed adverse selection, moral hazard model, we show that optimal contract design may differ significantly between procurement and regulatory policy environments. We model risk averse landholders to preserve a key feature of the policy environment. These findings have implications for the design of pollution reduction schemes and the rehabilitation of environmental assets.

**Key words:** adverse selection, biodiversity, contract theory, moral hazard, procurement.

## 1. Introduction

Payments for environmental services (PES) create incentives for private agents to protect and enhance environmental assets. Despite the growing number of programs that adopt PES, the design of markets for environmental services tends to be informal, with little attention to incentives or to market efficiency (Stavins 2003; Ferraro and Simpson 2006).

Environmental procurement is characterised by adverse selection and moral hazard issues (Ferraro 2008). There are two dominant areas of research within the PES literature. A number of authors have explored contract design in the context of government procurement. This literature generally refines contracts according to a particular environmental application or focuses on a particular aspect of contract design (Smith 1995; Ozanne *et al.* 2001; White 2002; Antle *et al.* 2003; Crepin 2005; Ozanne and White 2007). The key feature of this literature is that it takes PES as given.

There is also a literature that compares government policies in the presence of adverse selection and moral hazard. PES are not taken as given, and the mechanism design approach is contrasted with regulatory programs, or fixed-price schemes. Ferraro (2008), for example, compares policies designed to overcome asymmetric information, including attempts to gather information on costly-to-fake signals, screening contracts and procurement auctions. Moxey *et al.* (1999) demonstrate that a menu of

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contracts incurs lower costs than one-on-one negotiation and simulates an example for landholders reducing their nitrogen fertiliser load. (See Smith (1995), Latacz-Lohman and Van der Hamsvoort (1998), White (2002) for other examples.)

It is therefore the case that most research has been carried out in the context of a single government program and usually procurement on behalf of the public. We are interested in the case where multiple government programs coexist and are designed to tackle the same environmental issue. We study and compare contract design for three policy-induced markets:

1. Public procurement: the government wishes to enhance environmental assets by writing contracts with low-cost landholders. The revenue will be raised by taxation, and the government wishes to maximise the welfare of all agents, both sellers and buyers (the taxpayers).
2. Private PES: a private firm wishes to purchase environmental services to satisfy regulatory requirements. For example, a firm may need to satisfy offset regulations. The firm plans to make an investment that will cause environmental damage. Regulation obliges the firm to purchase an offset and ameliorate the environmental damage by contracting with a landowner to protect a comparable environmental asset. The firm maximises its profit.
3. Private purchase through a government market: to facilitate environmental offsets and to enhance oversight, the government manages a market for environmental contracts. Private firms purchase offset contracts through the market. The government writes the contract with the landowner. It maximises aggregate welfare, but does not need to raise revenue, because it is only an intermediary.

The environmental problem is common across the contracts; we are interested in the particulars of each policy environment. The question we ask is this: will the optimal contract differ systematically in these three cases, and if so, how will they differ? We apply the optimal procurement model of Laffont and Tirole (1986, 1987) to compare the contract design in these different procurement settings and also account for risk aversion on the part of the landholder. This is a simple, flexible framework in which to examine variations in the policy environment.

This model has been used in a wide variety of other procurement contexts: see the survey article Laffont (1994) and the monograph Laffont and Tirole (1993). It deals both with the necessity to provide appropriate incentives for agents to take unobservable private actions and the need to identify and transact with the lowest cost providers. It also provides practical guidance on implementation: a menu of linear contracts, with entry determined by a preliminary auction. Although no environmental procurement scheme of which we are aware has implemented all of these features, many are

recognisable in some widely used schemes, such as the BushTender and EcoMarket programs in Victoria, Australia (Stoneham *et al.* 2007). This model is also influential in schemes that are currently being designed.<sup>1</sup> Because this mechanism is optimal, subject to its assumptions, it provides a very useful benchmark.

For context, we provide two examples. The first is biodiversity procurement, in particular biodiversity on private land. We are concerned with the following problem, which is described in Stoneham *et al.* (2007). Valuable biodiversity assets (remnant habitat) are located on private land. The value of an asset,<sup>2</sup> as well as the actions that can be taken to protect it, can be determined by a visit from an ecologist. Some of these actions may be verifiable (for example erecting a fence), but some may be private and difficult to verify (for example reducing herbicide and insecticide use).<sup>3</sup> Whether or not the asset has been protected can be verified, with some error, by the ecologist after some time (for example, from the prevalence of certain species). The Victorian Government makes PES to increase the public stock of biodiversity assets. There are also regulatory offset requirements that give rise to the private purchase of biodiversity offsets. However, because environmental assets are heterogeneous and transactions must match 'like with like', both buyers and sellers of offsets face a complicated matching and bundling problem. The Victorian government operates a matching market that facilitates matching and bundling transactions between buyers and sellers of offsets. The offset scheme and matching market are described in Nemes *et al.* (2008).

The second context is the purchase of carbon biosequestration services from private landholders. Climate change policies give rise to three potential markets for biosequestration services, comparable to the three markets for biodiversity procurement. When governments wish to procure biosequestration services to reduce their nation's net carbon emissions, the government will fund these purchases with general taxation revenue and maximise aggregate welfare. To satisfy regulatory requirements, a profit maximising private entity may purchase biosequestration services to offset the entity's excess carbon emissions. To satisfy quality concerns and to protect the integrity of the carbon cap, governments with reduction commitments may opt to design and certify the biosequestration contracts traded in the private market for carbon emissions offsets. Under these circumstances, governments

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<sup>1</sup> For example, a project in South India funded by the National Tiger Conservation Authority and Critical Ecosystems Partnership Fund.

<sup>2</sup> By value, we mean the social willingness to pay, as expressed through the political system and the formation of government policy. We make no claim as to whether this reflects true social value. We avoid any discussion of the optimum quantity of public goods. We are concerned only that what is purchased is purchased at minimum cost.

<sup>3</sup> This approach is consistent with White and Sadler (2012, p. 2), which also examines biodiversity contracts with a fixed payment for observable actions (fencing) and a variable payment for changes in the species metric.

would write contracts that maximise aggregate welfare but are paid for by private funds.<sup>4</sup>

## 2. The model

We use a version of Laffont and Tirole's basic procurement model (Laffont and Tirole 1986), which we modify to allow for risk aversion.<sup>5,6</sup> Empirical studies overwhelmingly conclude that farmers are risk averse. These results appear robust to the context of both developing and developed countries and to different risk specifications and estimation methodologies. (See, for example, Antle (1987), Dubois and Vukina (2004), Gómez-Limón *et al.* (2003), Groom *et al.* (2008) and Myers (1989) for studies in different contexts.) Given that risk aversion is a key feature of the policy environment, it is useful to see how it impacts on the optimal contract, and whether it affects the standard interaction between the contracting and auction mechanisms. We include key notation and results, but relegate most workings to the Appendix.

This model allows for voluntary participation, adverse selection and moral hazard, with the advantage that the relationship between contract design and auction design is particularly transparent (Laffont and Tirole 1987). We will follow the notation of their monograph (Laffont and Tirole 1993), which differs in some respects from the original paper. By varying the principal's objective function, we can examine – in a unified manner – the impact of three different contracting environments on the efficient contract. The key parameters are  $\theta$ , the weight placed by the principal on the welfare of the agent, and  $\lambda$ , the dead-weight cost of raising taxation revenue. We assume that the government is concerned with maximising aggregate welfare and is unconcerned about the distribution of information rents. For public procurement, therefore,  $\theta = 1$ , while  $\lambda > 0$  (scenario 1 in the examples described in the introduction above). For private procurement,  $\theta = \lambda = 0$ , as the private principal maximises their own profit (scenario 2 above). In the government-facilitated offset market, the government designs contract to maximise welfare and hence  $\theta = 1$ , while  $\lambda = 0$ , as the contracts are purchased with private funds (scenario 3 above).

A very convenient feature of the Laffont Tirole framework is that when the principal is dealing with many agents, the problem can be decomposed into

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<sup>4</sup> Some governments have already moved to create certification schemes for offset contracts, including the Australian Government's National Carbon Offset standard or the United Kingdom's Quality Assurance Scheme (QAS) for carbon offsets. Until 2012, signatories to the Kyoto Protocol (including Australia, New Zealand and the European Union) bear responsibility for offsets credited to national carbon accounts and for ensuring that biosequestration projects are compliant with Kyoto's Clean Development Mechanism.

<sup>5</sup> For convenience, we reinterpret effort as output-enhancing rather than cost-reducing. This is an immaterial rewriting of the model.

<sup>6</sup> We also restrict ourselves to contracts that can be implemented by a menu of linear contracts. This facilitates dealing with risk aversion. Under risk-neutrality, this assumption is not needed (Laffont and Tirole 1993).

two parts. First one designs the contract appropriate to a single principal, single agent transaction. The optimal mechanism when dealing with multiple agents is then to auction the right to sign such a contract (Laffont and Tirole 1987). This separability holds in our context, so we will begin with the single agent problem.

## 2.1. Contracting with a single agent

We will use the biodiversity example in discussing the structure of the contract. The application to the biosequestration example is straightforward. All key parameters are summarised in Table 1.

A participating agent can produce measured environmental output  $x + \varepsilon = \beta + e + \varepsilon$ , where  $\beta$  is the agent's type,  $e \geq 0$  is effort exerted by the agent, and  $\varepsilon$  is a random shock with mean zero and variance  $\sigma^2$  reflecting the fact that production is risky. It may also incorporate risk introduced by errors in measuring output. The effect of either type of risk is similar: an upward shift in the effort curve due to the cost of risk-bearing, so we do not distinguish between them in the model. The type  $\beta$  is a parameter in the agent's conservation production function. Although the government can estimate and value the quantity of remnant habitat, agents hold private information on the unique mix of technology and inputs that will influence the rehabilitation and protection of vegetation. Through exertion of effort  $e$ , the agent can improve the quality of remnant vegetation. Both  $e$  and  $\beta$  are private information, known only to the agent, but total output  $x$  can be measured (possibly with some error incorporated in  $\varepsilon$ ) by the principal. We assume that the type  $\beta$  is distributed, independently and identically, in the interval  $[\underline{\beta}, \bar{\beta}]$  with distribution function  $F(\beta)$  and density function  $f(\beta)$  and that the inverse hazard rate  $h(\beta) = 1 - F(\beta)/f(\beta)$  is non-increasing. We assume that the principal is risk-neutral.

The agent's utility  $v(t, e) = g(t) - \psi(e)$  is separable in the income transfer  $t$  that will be made by the principal and in effort  $e$ , and is concave (risk averse) in  $t$ .

**Table 1** Key parameters

$\lambda$	Cost of raising revenue through taxation
$\theta$	Weight that principal places on Agent utility
$\beta$	Agent type
$x$	Measured output
$e$	Agent's effort
$\varepsilon$	Random shock to output
$\sigma^2$	Variance of random shock
$\psi$	Disutility of effort function
$c$	Risk premium
$\eta$	Coefficient of risk aversion

We can rescale the agent's utility function so that with a random transfer  $z$  and an effort level  $e$ , utility is of the form<sup>7</sup>

$$\tilde{v}(z, e) = \bar{z} - c(z) - \psi(e). \quad (1)$$

The agent's utility depends on the expected transfer  $\bar{z}$ , subject to adjustments for a risk premium  $c(z)$  and for the disutility of effort  $\psi(e)$ . Following Laffont and Tirole, we will assume that disutility of effort is increasing and convex in effort:  $\psi(0) = 0$ ,  $\psi(e) \geq 0$ ,  $\psi'(e) \geq 0$ , and  $\psi''(e) > 0$ . We will also assume, as do they, that  $\psi'''(e) \geq 0$ .<sup>8</sup>

In general, if the variance is small, then the risk premium takes the form

$$c(z) = \frac{1}{2}\eta \text{Var}(z), \quad (2)$$

where  $\eta$  is an appropriate coefficient of risk aversion (Newbery and Stiglitz 1981, pp. 69–80) and depends upon wealth and background risk (Franke *et al.* 2004). In the interests of tractability, we assume that the impact of the contract on the agent's risk and wealth position is not sufficient to significantly affect their risk preferences, and we will treat  $\eta$  as a constant. This is reasonable provided that the agent's risk and return exposure through the contract are not dominant in the agent's portfolio of investments, which seems a reasonable assumption in the policy context.

The principal offers a menu of linear contracts.

$$T(x + \varepsilon, \hat{\beta}) = a(\hat{\beta}) + b(\hat{\beta})(x + \varepsilon), \quad (3)$$

contingent on announced type  $\hat{\beta}$  and linear in observed output  $x + \varepsilon$ . If the agent announces type  $\hat{\beta}$  and chooses effort  $e$  consistent with expected output  $x = e + \beta$ , then they will receive a transfer  $z$  with mean  $a(\hat{\beta}) + b(\hat{\beta})(e + \beta)$  and variance  $b(\hat{\beta})^2 \sigma^2$  and achieve utility

$$U(\hat{\beta}, e, \beta) = \tilde{T}(x, \hat{\beta}) - \psi(e), \quad (4)$$

where

$$\tilde{T}(x, \hat{\beta}) = \left( a(\hat{\beta}) - \frac{1}{2}\eta b(\hat{\beta})^2 \sigma^2 \right) + b(\hat{\beta})x, \quad (5)$$

is the implied risk-adjusted menu of contracts in the agent's decision space.  $\tilde{T}(x, \hat{\beta})$  is linear in expected outcome (or equivalently effort  $e$ ). We note that the slopes of the contracts  $T(x + \varepsilon, \hat{\beta})$  and  $\tilde{T}(x, \hat{\beta})$  are the same, but that the

<sup>7</sup> By the separability assumption, we can re-label indifference curves to linearise  $g(z)$  (see, for example, Mas-Colell *et al.* 1995, p. 45).

<sup>8</sup> This assumption on third derivatives is standard in this class of models and required to avoid complications arising from non-convexity.

intercept of  $\tilde{T}(x, \hat{\beta})$  is adjusted by an amount that depends on both  $a(\hat{\beta})$  and  $b(\hat{\beta})$  to accommodate the cost of risk-bearing. We notice that, irrespective of  $\hat{\beta}$ , the optimal effort level  $e$  does not depend on the variance  $\sigma^2$ .<sup>9</sup> Output risk, or measurement risk, affects participation but not the optimal choice of action conditional on participating.

We write

$$u(\beta) = \max_{\hat{\beta}, e} U(\hat{\beta}, e, \beta), \quad (6)$$

for the information rent earned by an agent of type  $\beta$ . We write  $e(\beta)$  for the optimal effort function implied by the contract and  $x(\beta) = e(\beta) + \beta$  for the implied expected output. We will write

$$t(\beta) = a(\beta) + b(\beta)x(\beta), \quad (7)$$

$$\tilde{t}(\beta) = t(\beta) - \frac{1}{2}\eta b(\beta)^2\sigma^2, \quad (8)$$

for the expected transfer and the risk-adjusted expected transfer, respectively. To reduce notation, we will when convenient drop the argument  $\beta$  and write  $x, t, \tilde{t}, e, u, a, b, f, F, h$ , instead of  $x(\beta), t(\beta), \tilde{t}(\beta), e(\beta), u(\beta), a(\beta), b(\beta), f(\beta), F(\beta), h(\beta)$ , and we will denote differentiation with respect to  $\beta$  by a dot.

The agent's utility depends on  $x$  and  $\tilde{t}$ , and as  $\beta$  varies, the contract  $(x(\beta), \tilde{t}(\beta))$  traces out a locus, the contract curve, in agent's  $(x, \tilde{t})$  space. The slope of the contract curve is  $\frac{d\tilde{t}}{dx} = \frac{\dot{\tilde{t}}}{\dot{x}} = \psi'(e)$ . This contract curve is the envelope of the menu of linear contracts  $\tilde{T}(x, \hat{\beta})$ .<sup>10</sup>

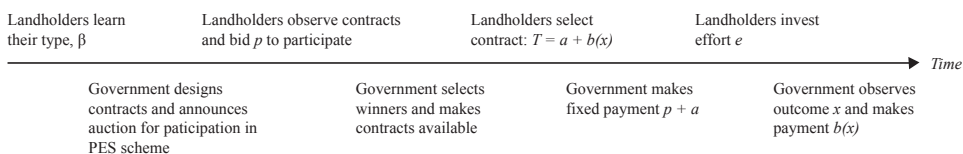
The principal's payoff depends on  $x$  and  $t$ ; she chooses a contract  $(x, t)$  (and hence implicitly  $e$  and  $u$ ), subject to incentive compatibility and individual rationality constraints, to maximise the objective

$$\max_{\{x(\cdot), u(\cdot)\}} \int_{\underline{\beta}}^{\bar{\beta}} \{x - (1 + \lambda)t + \theta u\} dF, \quad (9)$$

where  $\lambda$  is the cost of raising the revenue  $t$ , and  $\theta \in [0, 1]$  is the weight placed by the principal on the agent's utility. We shall interpret the value of these parameters in the policy environments of interest below. After an integration by parts, the principal's problem becomes

<sup>9</sup> This is because of the additive specification of the error  $\varepsilon$  and our assumption that, for wealth variations implied by the contract,  $\eta$  is constant.

<sup>10</sup> With quadratic risk aversion there is no need to consider random transfers. This is also true under more general forms of risk aversion when the contract is convex in contract space, and can be approximated by a menu of linear contracts.



**Figure 1** Timeline.

$$\max_{\{e(\cdot)\}} \int_{\underline{\beta}}^{\bar{\beta}} \left\{ e + \beta - (1 + \lambda) \left( \psi(e) + \frac{\eta \sigma^2}{2} \psi'(e)^2 \right) - (1 + \lambda - \theta) \psi'(e) h \right\} dF. \quad (10)$$

We note the term containing  $\eta$  in the expression for the virtual surplus; it is through this term that risk aversion enters into the contracting problem.

By a standard argument,<sup>11</sup> the integrand is concave in  $e$ , and the optimal effort is determined at interior points by the principal's first-order condition. It can then be verified that the contract curve is convex in  $(x, \hat{t})$  space, confirming that the contract may be implemented by a menu of linear contracts, tangent to the contract curve.

A linear contract is of the form  $T(x) = a + bx$ , promising a fixed upfront payment  $a$  and a conditional payment  $bx$  that depends upon the output achieved. Because typically  $0 \leq b \leq 1$ , this takes the form of a surplus sharing rule. It is often more convenient to write this in the form  $T(x) = b(x - x_0)$ , where  $x_0 = \frac{a}{b}$  can be interpreted as an output threshold. The interpretation of this contract is that the agent must achieve the target  $x_0$  and then receives a proportion  $b$  of the output beyond the threshold. A menu of contracts would specify an output target  $x_0(\beta)$  and a sharing proportion  $b(\beta)$  for each possible type  $\beta$ . The agent would select from this menu by nominating a type  $\beta$ . Incentive compatibility implies that they would actually find it optimal to nominate their type truthfully.

If some of the agent's actions are in fact verifiable, then these can be incorporated into the constant term. The contract is then of the form  $T(x) = a + b(x - x_0)$ , where  $x_0$  is an output target,  $a$  is an agreed payment for taking the verifiable actions, and  $b$  is a sharing proportion for output beyond the target (Figure 1).

## 2.2. Contracting with many agents

We now consider the case of multiple agents.<sup>12</sup> Under risk-neutrality, contract design is particularly simple (Laffont and Tirole 1987). The optimal

<sup>11</sup> See for example chapter 2 of Laffont and Tirole (1993).

<sup>12</sup> We have not just multiple agents but multiple objects, because multiple contracts will be signed. But this introduces no new complexity, because the agents bid only for a single contract. For a discussion of this point with respect to multi-unit auctions, see (Krishna 2002, chapter 12).

mechanism can be implemented by conducting a preliminary auction of the right to participate and then offering winners exactly the menu of contracts derived above for the single-agent case. Because this is a procurement contract, it is natural to treat the bid as a payment from the auctioneer to the agent that the agent would be willing to accept in order to participate. If an agent wins the right to participate, bidding  $p$ , and then selects the contract  $a + bx$ , then the total fixed payment will be  $p + a$ , and the payment to the agent will be  $p + a + bx$ .

The effect of the auction is to contract the type space of the agents participating in the contract to  $[\beta_0, \bar{\beta}]$ , where  $\beta_0$  is the type of the highest non-participating agent. Thus, the competition between agents in the preliminary auction reduces, but does not entirely eliminate, uncertainty about the agents' types at the contracting stage. This residual uncertainty is managed through the contract design. An important implication is that contract design is invariant to the number of participants in the auction.

Under risk aversion, the analysis with multiple agents is not so straightforward, except in one case that we will focus on: if the cost of effort function  $\psi(e)$  is quadratic. This includes the important case of constant marginal cost of effort. We write

$$\phi(e) = \psi(e) + \frac{\eta\sigma^2}{2}\psi'(e)^2, \quad (11)$$

for the total cost, including risk-bearing. When the cost of effort is quadratic, the problem is isomorphic to the risk-neutral case, but with the hazard rate adjusted by a constant factor, and we obtain the basic separability result. In these cases, the optimal mechanism is again the use of a preliminary auction of the right to participate, with participants choosing a contract from the menu derived above. The design of the menu of contracts does not depend on the number of potential participants in the mechanism.

### 3. An example

We illustrate with a numerical example. Let us assume that  $\beta$  is distributed uniformly on the interval  $[\underline{\beta}, \bar{\beta}]$ , so  $h(\beta) = (\beta - \underline{\beta})/(\bar{\beta} - \underline{\beta})$ , and that  $\psi(e) = \frac{e^2}{2}$ . In this case, the principal's first-order condition is

$$1 = (1 + \lambda - \theta)(1 - \beta) + (1 + \lambda)(1 + \eta\sigma^2)e, \quad (12)$$

so the contractual level of effort is

$$e = \frac{1 + (1 + \lambda - \theta)(\beta - 1)}{(1 + \lambda)(1 + \eta\sigma^2)}. \quad (13)$$

The principal's virtual surplus (the expression in the integrand (Eqn 10) is

$$k(\beta) = \frac{(1 + \lambda - \theta)^2 \beta^2 + 2 \left( 1 + \theta + (1 + \lambda) \eta \sigma^2 - (\theta - \lambda)^2 \right) \beta + \frac{1}{2} (\theta - \lambda)^2}{(1 + \lambda)(1 + \eta \sigma^2)}, \quad (14)$$

which is convex and non-negative at  $\beta = 0$ . A simple calculation shows that  $k(\beta)$  is minimised at

$$\beta_0 = - \frac{(1 - \lambda^2) + (\theta - \theta^2) + 2\theta\lambda + \eta\sigma^2(1 + \lambda)}{(1 + \lambda - \theta)^2},$$

which is negative provided that  $0 \leq \theta \leq 1$  and  $0 \leq \lambda \leq 1$ .

Thus, if, for example,  $[\underline{\beta}, \bar{\beta}] = [0, 1]$ , then we have  $k(\beta)$  non-negative over the whole interval  $[0, 1]$ , and  $u$  can be calculated by integrating  $\dot{u} = \psi'(e)$  from zero, yielding

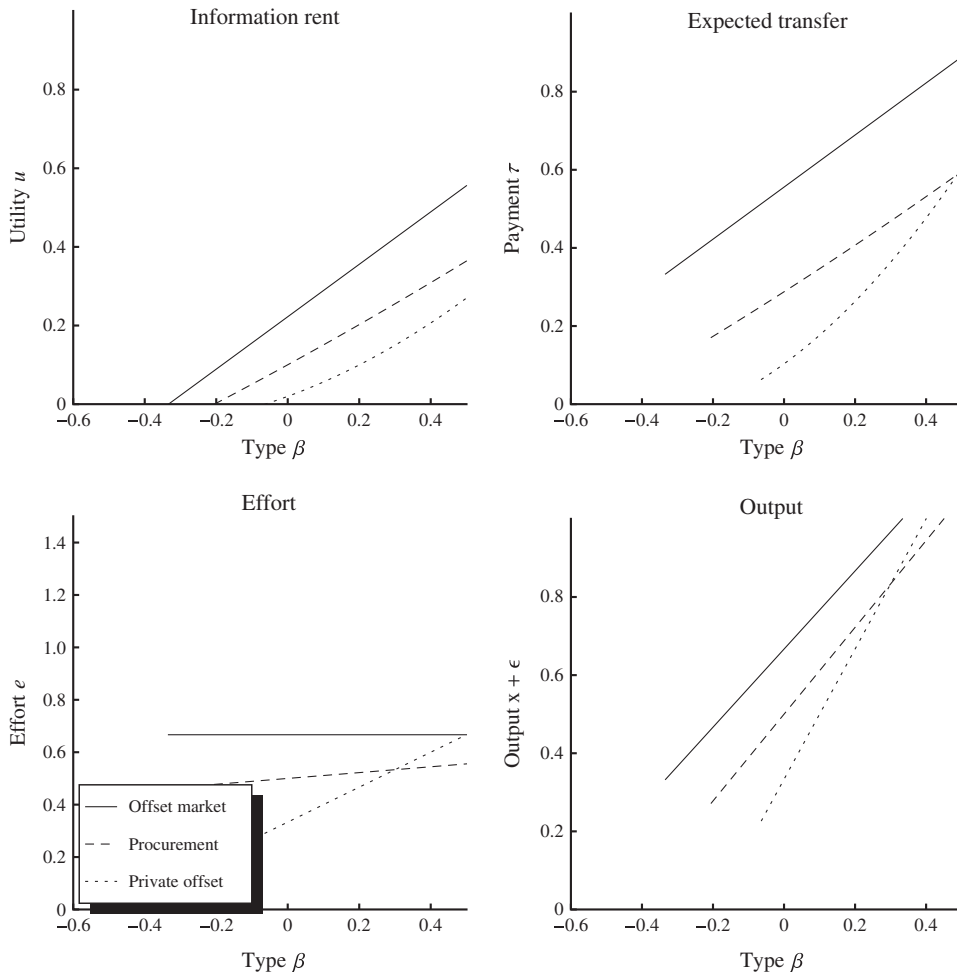
$$u = \frac{(1 + \lambda - \theta) \beta^2 + 2(\theta - \lambda) \beta}{2(1 + \lambda)(1 + \eta \sigma^2)}. \quad (15)$$

In general, the virtual surplus will not be non-negative over the whole interval. There will be some cut-off type  $\beta_0$  such that  $k(\beta_0) = 0$ . The principal will wish to exclude all types below this, and  $u$  will be determined by integrating from  $\beta_0$ . The transfers  $t$  and  $\tilde{t}$  are readily calculated from  $e$  and  $u$ .

We show in Figures 2–5 the behaviour of variables of interest for typical parameters. We assume that types are uniformly distributed in the interval  $[-1, 0.5]$  (this illustrates a scenario where many landholders own a significantly degraded asset, while some may hold assets of considerable value), the effort function is quadratic, and the variance of output is  $\sigma^2 = 1$ . In Figures 2 and 3, we model risk averse agents with a constant coefficient of risk aversion  $\eta = 0.5$ , and in Figures 4 and 5, we model risk-neutral landholders, setting  $\eta = 0$ .

To make the example as relevant as possible, we consider the three policy-based markets discussed in the introduction.

1. Government procurement: the government is benevolent, putting equal weight on all parties ( $\theta = 1$ ), and the dead-weight cost of raising revenue through taxation is  $\lambda = 0.2$ . This contract is shown with a dashed line.
2. Private procurement to meet regulatory requirements:  $\lambda = \theta = 0$ . This contract is shown with a solid line.
3. The government designs the contract traded in its offset market. As the offset is purchased by the developer, there is no funding distortion, and we set  $\theta = 1$ ,  $\lambda = 0$ . This contract is shown with a dotted line.

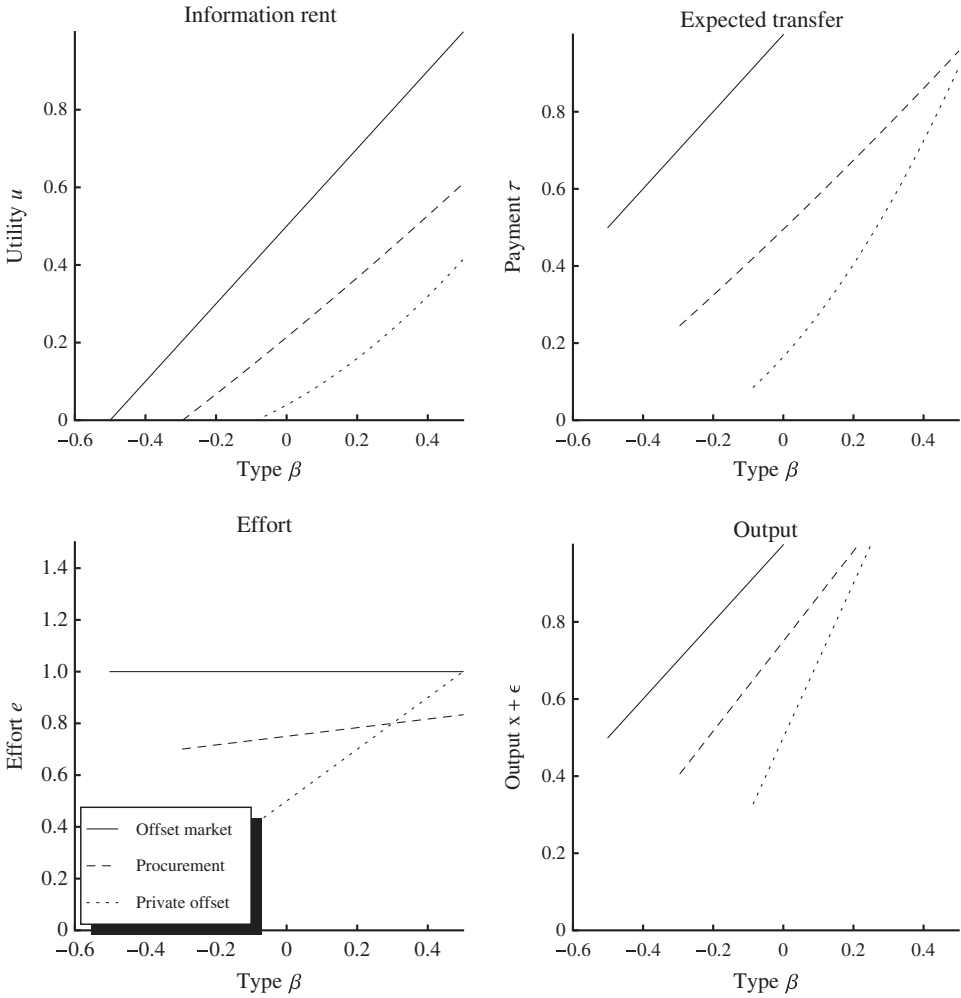


**Figure 2** Effort, outcomes and transfers to type  $\beta$ , risk averse landholder.

Figures 2 and 4 show effort, output, transfer and information rent profiles by type, for the risk averse and risk-neutral cases, respectively. Figures 3 and 5 show the optimal contracts under both risk preferences. This contract may be represented as a nonlinear contract in either observable  $(x + \epsilon, t)$  output-transfer space or in the agent's  $(e, u)$  effort-utility decision space, or as a menu of linear contracts.

It is clear from these figures that the optimal contract is different in each policy setting and under different risk preferences.

We find that contract design is simplest for the case of government-administered offset markets, and it is easy to see why this should be so, especially if agents are risk-neutral. The government wants to maximise total surplus and does not care how it is allocated. In this case, there is no need to screen agents through the contracting framework, and the government is happy for the agent to retain all the surplus (this surplus may be extracted

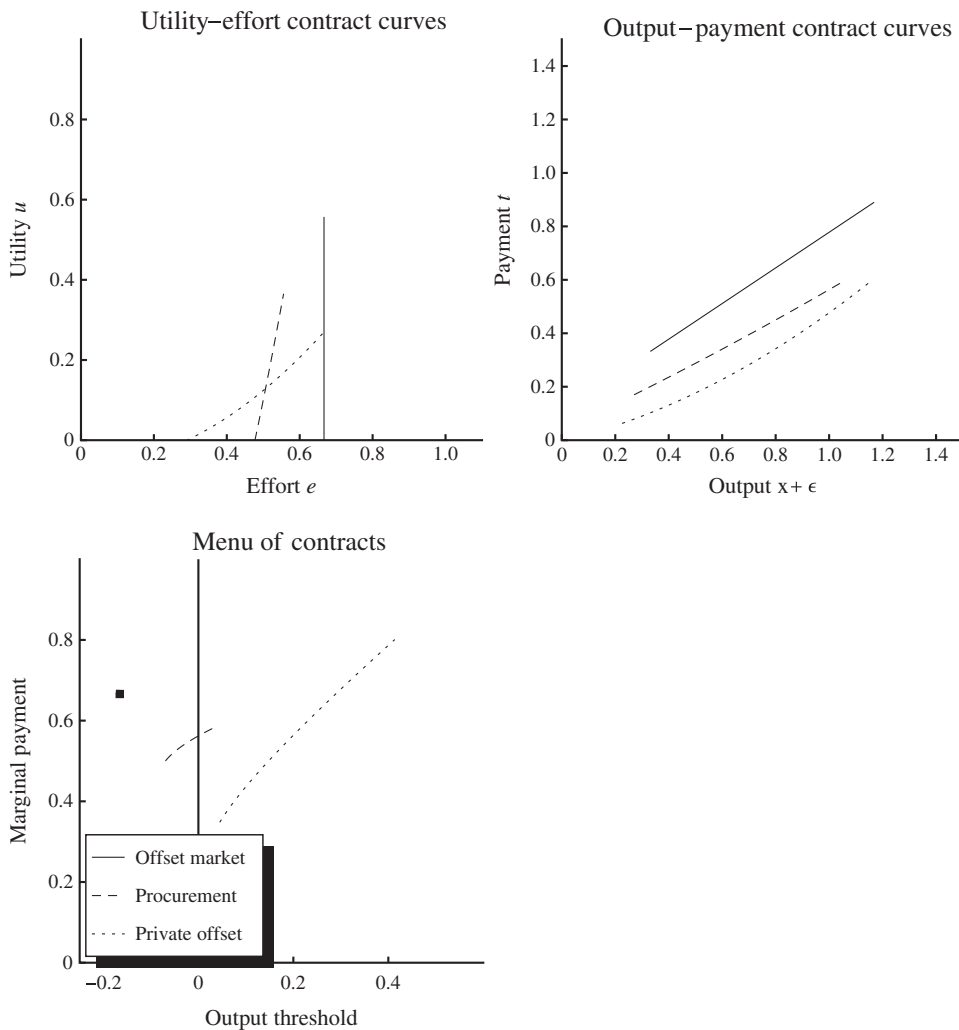


**Figure 3** Optimal Contracts, risk averse landholder.

separately, through a preliminary auction, as discussed above). The natural solution is to ‘sell the project to the agent’, allowing the agent to retain all the surplus at the margin and hence to internalise all externalities. The principal thus offers a simple linear pooling contract<sup>13</sup> inducing the first best effort level. This simple contract will have two components: a fixed component  $a$  (which may be either positive or negative) and a variable component  $b$ . Risk aversion is unrelated to type under our assumptions, so it is not useful to screen agents by exposure to risk, and a simple pooling contract is still optimal.

In contrast, the private purchaser has a strong incentive to minimise transfers to the agent ( $\theta = 0$ ) and implements a diverse menu that separates types

<sup>13</sup> That is to say, the slope of the contract is the same for everyone; the intercept, which is implicitly determined at the auction stage, may vary between types.



**Figure 4** Effort, outcomes, and transfers to type  $\beta$ , risk-neutral landholder.

strongly, inducing a wide variation in effort levels. Such screening reduces information rents and the payment to agents, but potentially induces lower effort levels.

The government procurement contract is intermediate in structure between the private procurer and the offset market contract. The government has an incentive to minimise transfers to the agent because of the distortionary cost of raising revenue ( $\lambda = 0.2$ ). It also implements a screening contract, but one that screens less aggressively than that of the private developer.

Under risk aversion, the key differences between optimal contracts are preserved. Across all environments, the slope  $b$  of the optimal contract will be less steep than under risk-neutrality. This is demonstrated in the Output-Payments Contract Curves in Figures 3 and 5. Because it becomes more

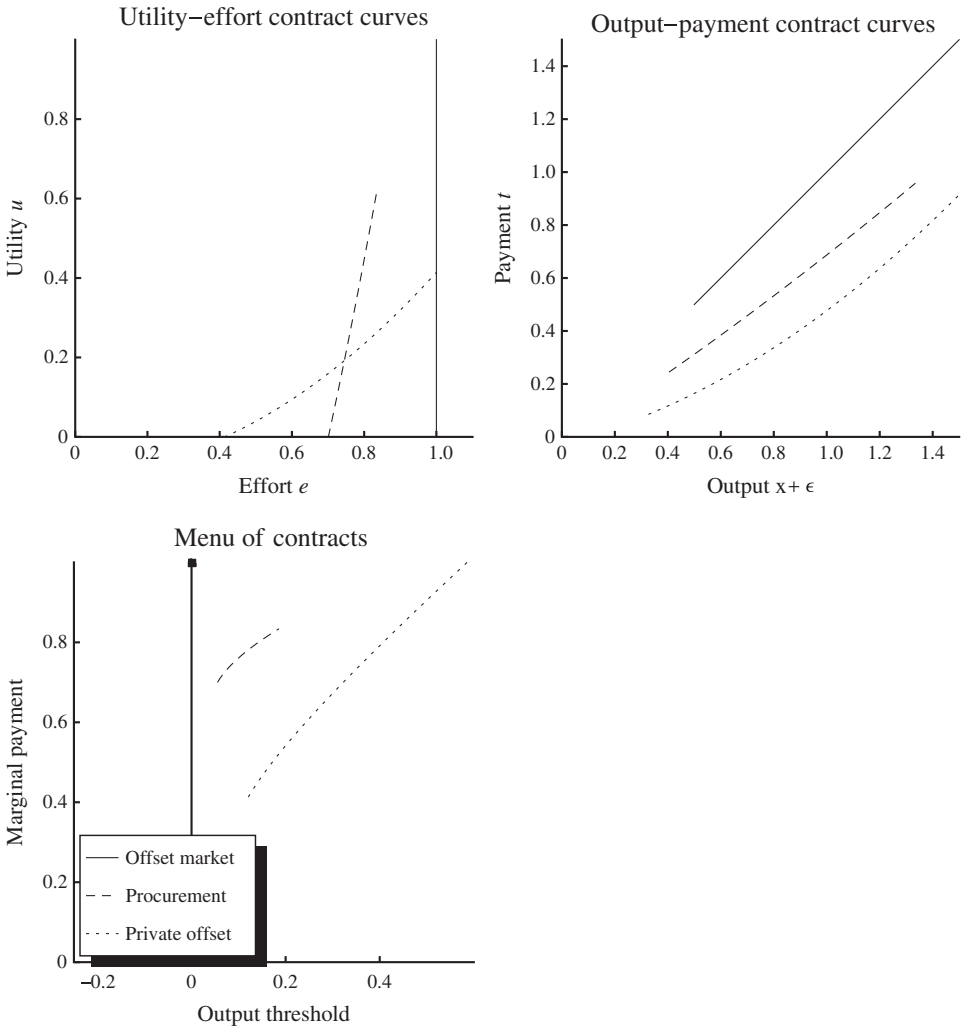


Figure 5 Optimal Contracts, risk-neutral landholder.

costly to induce effort, the optimal level of effort is lower under all three contracts, as demonstrated by comparing the effort-type curves in Figures 2 and 4. However, the cost of accommodating risk aversion does not affect the optimal contracts uniformly and interacts with existing differences between the principal's objective function in each regulatory environment. Relative to each market's risk-neutral case, risk aversion affects the optimal contract in government-managed markets more than it affects private contracts. Government-managed contracts optimise total surplus, which leads to more generous transfers than contracts in the private market. Under risk aversion, the government has more scope to adjust transfers in response to the higher costs of inducing effort. In contrast, private principals always minimise transfers to agents, and so the adjustment to accommodate risk aversion is

not as pronounced. The net effect of risk aversion is to reduce the variation between contracts across the three policy-induced markets.

#### 4. Discussion

Auctions for environmental payments are increasingly important and can be used to enhance the stock of environmental assets or to facilitate trade in offset markets. Standard procurement models can be adapted to provide a workable framework for contract design in such markets.

Our modelling exercise leads to useful insights into the institutional design problem across three policy-induced markets for environmental services. When designing contracts for the offset market, the government offers a simple linear contract, characterised by an up-front payment and a relatively high performance incentive. The private purchaser offers a wide range of linear contracts, characterised by an output target and a range of performance incentives, some of them quite weak. The government purchaser offers a menu of contracts that is intermediate between the two.

We return briefly to our two examples. Where biodiversity or biosequestration offset schemes complement government procurement programs, our model suggests that contracts for the offset matching markets should be simpler in structure and provide harder incentives than those designed for public procurement. Where governments introduce emissions trading schemes to cap carbon emissions, or biodiversity offset requirements for developers, a market for private offset contracts will emerge. Our model indicates that these private contracts will be weaker than those a welfare-maximising government would design for the same purpose. For governments concerned about the welfare implication of environmental offset regulations, there are potential welfare gains that can be secured by designing the procurement contracts traded in the offset market.

Contract design is thus sensitive to the institutional framework: contracts that make sense under one regulatory framework cannot necessarily be applied without thought to another, despite the apparent similarity of the environmental problems. To maximise social welfare, governments need to consider the policy context, as well as the contracting challenges that are unique to each environmental problem.

In contrast, at least within the theoretical framework used here, contract design is not sensitive to the number of bidders. Contract design need not differ according to the intensity of competition, which is harnessed by auctioning the right to participate. If there are many potential suppliers, then they will bid down the information rents in the auction. If the asset has no good substitutes and there are few potential suppliers, then rents will be higher, and the designer will be relying more on the screening properties of the contract to minimise rents.

Any actions that can be taken to reduce exposure to risk will lead to more favourable (steeper) contracts from the principal's point of view. For

example, where it is efficient, some level of insurance could be built in (for example, output targets might be conditional on drought conditions, bushfires, or other events beyond the landowner's control). The reduction of measurement and monitoring risk through appropriate science and technology will also lead to more favourable contracts from the principal's point of view.

The model we have used facilitates a simple and elegant examination of the interaction between three different contracting environments and the efficient contract. The main benefit of this exercise is to help structure the way economists and policy-makers think about contract design for policy markets. It would be useful to know how robust these conclusions are if we relax the assumptions embedded in this specification, although it is unlikely that closed form solutions can be found, and numerical simulation would be required. Empirical evidence on the validity of these assumptions would be valuable, particularly regarding key inputs, including the degree of risk aversion, the distribution of types in the population and the shape of the effort curve. With respect to the distribution of types, there is a growing body of data from environmental procurement auctions which may be amenable to econometric investigation (Paarsch and Hong 2006). Getting information on the effort function and the production function for environmental goods may require a different approach. Biophysical modelling and simulation are widely used to model agricultural systems and may be able to be adapted to model the production of habitat and biodiversity assets.

Policy design for procurement of environmental services needs to take a position, at least implicitly, on all of these matters. Because there is little empirical evidence, this analysis suggests that good practice will address this need for data through the use of simulation and biophysical modelling, through the use of pilot studies and by incorporating evaluation and parameter estimation into policy design.

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### Appendix

All parameters and key features of the model are defined in Section 1 of the text.

The principal offers a menu of linear contracts:

$$T(x + \varepsilon, \hat{\beta}) = a(\hat{\beta}) + b(\hat{\beta})(x + \varepsilon), \quad (\text{A.1})$$

contingent on announced type  $\hat{\beta}$  and linear in observed output  $x + \varepsilon$ . If the agent announces type  $\hat{\beta}$  and chooses effort  $e$  consistent with expected output  $x = e + \beta$ , then they will receive a transfer  $z$  with mean  $a(\hat{\beta}) + b(\hat{\beta})(e + \beta)$  and variance  $b(\hat{\beta})^2 \sigma^2$  and achieve utility

$$\begin{aligned} U(\hat{\beta}, e, \beta) &= \tilde{v}(a(\hat{\beta}) + b(\hat{\beta})(e + \beta + \varepsilon), e) \\ &= a(\hat{\beta}) + b(\hat{\beta})(e + \beta) - \frac{1}{2} \eta b(\hat{\beta})^2 \sigma^2 - \psi(e) \\ &= \left( a(\hat{\beta}) - \frac{1}{2} \eta b(\hat{\beta})^2 \sigma^2 \right) + b(\hat{\beta})(e + \beta) - \psi(e), \\ &= \tilde{T}(x, \hat{\beta}) - \psi(e) \end{aligned} \quad (\text{A.2})$$

where

$$\tilde{T}(x, \hat{\beta}) = \left( a(\hat{\beta}) - \frac{1}{2} \eta b(\hat{\beta})^2 \sigma^2 \right) + b(\hat{\beta})x, \quad (\text{A.3})$$

is the implied risk-adjusted menu of contracts in the agent's decision space.

$$u(\beta) = \max_{\hat{\beta}, e} U(\hat{\beta}, e, \beta), \quad (\text{A.4})$$

is the information rent earned by an agent of type  $\beta$ . We write  $e(\beta)$  for the optimal effort function implied by the contract and  $x(\beta) = e(\beta) + \beta$  for the implied expected output. We will write

$$\begin{aligned} t(\beta) &= \text{ET}(x(\beta) + \varepsilon, \beta) \\ &= T(x(\beta), \beta) \\ &= a(\beta) + b(\beta)x(\beta) \end{aligned} \quad (\text{A.5})$$

$$\begin{aligned} \tilde{t}(\beta) &= \tilde{T}(x(\beta), \beta) \\ &= a(\beta) + b(\beta)x(\beta) - \frac{1}{2} \eta b(\beta)^2 \sigma^2, \\ &= t(\beta) - \frac{1}{2} \eta b(\beta)^2 \sigma^2 \end{aligned} \quad (\text{A.6})$$

for the expected transfer and the risk-adjusted expected transfer, respectively.

As per the main text, and when convenient, we drop the argument  $\beta$  and write  $x, t, \tilde{t}, e, u, a, b, f, F$ , and we will denote differentiation with respect to  $\beta$  by a dot. By standard arguments Laffont and Tirole (1993), we have:

$$u = \tilde{t} - \psi(e), \quad (\text{A.7})$$

$$x = e + \beta, \quad (\text{A.8})$$

$$\tilde{t} = t - \frac{1}{2}\eta\sigma^2\psi'(e)^2, \quad (\text{A.9})$$

$$\dot{u} = \psi'(e), \quad (\text{A.10})$$

$$b = \psi'(e), \quad (\text{A.11})$$

$$\tilde{t} = \psi'(e)\dot{x}, \quad (\text{A.12})$$

$$\dot{x} \geq 0, \quad (\text{A.13})$$

$$u(\underline{\beta}) = 0, \quad (\text{A.14})$$

These are, respectively, the definitions of  $u$ ,  $x$  and  $\tilde{t}$  the envelope condition, the first- and second-order conditions, incentive compatibility and individual rationality. The slope of the contract curve is

$$\frac{d\tilde{t}}{dx} = \frac{\dot{\tilde{t}}}{\dot{x}} = \psi'(e).$$

This contract curve is the envelope of the menu of linear contracts  $\tilde{T}(x, \hat{\beta})$ .

The principal's objective function is

$$\max_{\{x(\cdot), u(\cdot)\}} \int_{\underline{\beta}}^{\bar{\beta}} \{x - (1 + \lambda)t + \theta u\} dF, \quad (\text{A.15})$$

Using integration by parts, making use of the envelope condition and the individual rationality constraint, the principal's problem becomes

$$\max_{e(\cdot)} \int_{\underline{\beta}}^{\bar{\beta}} \left\{ e + \beta - (1 + \lambda) \left( \psi(e) + \frac{\eta\sigma^2}{2} \psi'(e)^2 \right) - (1 + \lambda - \theta) \psi'(e) h \right\} dF. \quad (\text{A.16})$$

The integrand is concave in  $e$ , and the optimal effort is determined at interior points by the principal's first-order condition

$$1 = (1 + \lambda) \psi'(e) (1 + \eta\sigma^2 \psi'(e) \psi''(e)) + (1 + \lambda - \theta) h \psi''(e), \quad (\text{A.17})$$

The contract curve is convex in  $(x, \tilde{t})$  space, and the contract may be implemented by a menu of linear contracts, tangent to the contract curve.

Under risk aversion, the analysis with multiple agents is not straightforward, unless the cost of effort function  $\psi(e)$  is quadratic. This includes the important case of constant marginal cost of effort. We write

$$\phi(e) = \psi(e) + \frac{\eta\sigma^2}{2} \psi'(e)^2, \quad (\text{A.18})$$

for the total cost, including risk-bearing. The Hamiltonian (Eqn 10) can then be written

$$e + \beta - (1 + \lambda)\phi(e) - \frac{(1 + \lambda - \theta)}{(1 + \delta\eta\sigma^2)} \phi'(e)h, \quad (\text{A.19})$$

where  $\delta = \psi''(e)$ , which is a constant. The problem is then isomorphic to the risk-neutral case, but with the hazard rate adjusted by a constant factor, becoming  $\frac{h}{(1 + \delta\eta\sigma^2)}$ , and we obtain the basic separability result.