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Contract Design for Biodiversity Procurement

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Abstract

Market based instruments are proving effective in biodiversity procurement and in the management of regulatory schemes to preserve biodiversity. The design of these schemes brings together issues in auction design, contract theory, ecology, and monitoring. Using a mixed adverse selection, moral hazard procurement model, we show that optimal contract design may differ significantly between procurement and regulatory policy environments.

Keywords biodiversity, procurement, adverse selection, contract theory
JEL Codes D82, D86, Q57

The preservation of biodiversity, through the protection and enhancement of environmental assets, is an objective shared by governments around the world. Often these assets are on private land, but provide environmental services with a strong public good element. The management of these assets presents difficult public policy problems, since private landholders may not have the incentive to make socially optimal decisions. In response to this problem governments use a range of policies to influence landholders' behaviour, including regulation to prohibit actions that endanger, damage or deplete environmental assets, and incentive programs to increase investment in nature conservation; these programs include, for example, broad-based conservation subsidies, input subsidies and support for volunteer programs.

Regulation and simple incentive programs have in many cases proven to be relatively inefficient and ineffective, especially for non-point-source problems (see for example ANA (2001)), and a range of market oriented schemes have been introduced with the aim of improving economic efficiency. Examples include tradeable emission permit schemes for Sulphur, Nitrogen and Carbon (Tietenberg 2002), biodiversity procurement auctions (Stoneham, Chaudhri, Ha & Strappazzon 2007), and environmental offset markets such as the US EPA's wetlands offset program (BEST 2001) or the Victorian Bush Broker Scheme[1]. For a recent review of procurement in the context of biodiversity economics see Kontoleon, Pascual & Swanson (2007).

Market oriented schemes can be broadly classified into three types: public procurement of environmental services (where the government is the purchaser), private procurement of environmental services (where a private developer is purchasing an offset required in order to get regulatory approval for some development project), and markets designed to match private buyers and sellers of offsets. We will give examples of each of these types later in this paper. There are important design and architecture problems to be addressed for all of these environmental policy institutions.

One of the salient features of both private and public procurement programs for non-point-source outcomes is the delegation of conservation activities to private landholders. In these policy institutions the principal (whether the government or a developer) faces asymmetric information problems. Adverse selection is a problem because the principal cannot gauge the key characteristics of suppliers – for example, the principal cannot gather detailed information on the environmental characteristics of a site, or a supplier's opportunity cost of providing environmental services. Moral hazard is a problem because procurement of environmental services requires the supplier to undertake actions and to protect a site through time, and it is difficult for the principal to observe and monitor compliance with a contract.

[1] This is documented at http://www.dpi.vic.gov.au/dse/

Because environmental procurement is subject to exogenous risks (for example, drought, disease and predators), it is critical that contract design accounts for risk as well as for these asymmetrical information problems. Contract design (and therefore the incentive to comply with a contract) is fundamental to the environmental integrity of all these policy institutions.

Contract design for environmental services has been considered by a number of authors. For example, Antle, Capalbo, Mooney, Elliott & Paustian (2003) discuss contracts to procure carbon sequestration services, and Feng, Kurkalova, Kling & Gassman (2006) consider the design of conservation incentive schemes, but neither of these authors consider issues of asymmetric information or incentive compatibility. Following the foundational contribution of Baron & Myerson (1982) on regulation under asymmetric information, there has been a steadily growing literature on optimal environmental policy under asymmetric information. This literature reflects the importance of heterogeneity and highly disaggregated private information in the environmental sector, and the fundamental constraints that these impose on policy. Spulber (1988) consideres optimal quotas and taxes for a polluting industry under asymmetric information. Smith (1995) applies a model of this type to design a least cost mechanism to retire agricultural land for environmental purposes. Wu & Babcock (1996) study the optimal design of an input tax or subsidy in a model of joint production of agricultural production and a pollutant. Crepin (2005) models wetland procurement. Sheriff (2008) studies optimal regulation in the presence of political constraints.

There are common features in all of these models that make them inappropriate to model biodiversity procurement. While adverse selection is taken into account, these are all essentially single agent models in that universal participation is assumed. A multi-agent assumption, which would lead naturally to an optimal auction framework, would be more appropriate. More significant is the fact that these models do not address moral hazard. The actions that are procurred (for example, not collecting fallen firewood from a forest) are intrinsically difficult to observe, and are related by complicated and indirect means to desired outcomes (for example the presence and prevalence of certain species). Risk and uncertainty, both in the environmental production function and in the monitoring and measurement technology, are clearly important as well. We thus need a mixed model, incorporating multiple agents, risky production, adverse selection and moral hazard in order to to address these issues.

In this paper we apply a version of the Laffont & Tirole (1986) procurement model, modified to allow for a risk aversion. This model is very tractable, and sufficiently flexible to address the issues that we are interested in. We examine issues that arise in the design of contracts under different assumptions about the policy institution. The main question that we ask is whether one can design a common type of contract that can be used across a range of institutions (public procurement, private procurement, procurement by a market maker in an offset market), or whether contract design must be sensitive to the institutional framework.

In order to establish a concrete context, and to clarify the nature of the economic problems that we are endeavouring to solve through contract design, we first summarise what a typical biodiversity procurement and preservation scheme looks like in practice. We then formally address the contract design issue, and finally we discuss some practical implications of the model in a real world design context.

1 Biodiversity procurement

In order to establish a concrete context we will outline the background to, and the development of, a typical biodiversity procurement program in Victoria, Australia. In doing so we will focus on the various informational constraints, which are so pervasive in this area, and the variety of strategies that can be applied to address them. We will be particularly interested in clarifying which issues must be resolved through contract design, and which can be addressed elsewhere in the institutional design problem.

Since European settlement in the late eighteenth century there has been substantial biodiversity loss though settlement and the agricultural development of the Australian continent. By the end of the nineteenth century, increasing public awareness of the need to protect environmental assets led to the creation of national parks. However, many ecosystems – for example, extensive and diverse grasslands – lay outside such protection and were largely destroyed[2]. As a result some of Australia's rarest and most important ecosystems have been reduced to remnant habitat fragments on private land. As public awareness of this loss of biodiversity has increased, government has responded by taking increased responsibility for biodiversity management. Over the past decade State and Federal Governments have allocated well over $300 million to biodiversity and habitat-related initiatives, mostly relating to the management of assets on private land.

Traditionally the Victorian Government sought to preserve and rehabilitate biodiversity through broad-based, un-targeted conservation subsidies for volunteer programs and through regulatory prohibitions on any further damage to biodiversity assets. Both of these policies face incentive problems: regulation creates an incentive for landholders to conceal environmentally valuable biodiversity located on their land, and although voluntary conservation is extremely valuable, incentives for participants to create value over the longer term are weak or absent. In

[2] Since European settlement, 90 per cent of the native vegetation in the eastern temperate zone has been removed (ANZECC 2000).

addition, while voluntary measures are well meaning, these interventions may not always be supported by good science or directed to the highest value activities. In the last decade government has moved toward a market based approach to biodiversity rehabilitation based on scientific modelling and a formal application of economic design principles.

Biodiversity management presents difficult public policy problems; asymmetric information is the source of many of these difficulties. Information about the existence and status of biodiversity assets, about the potential actions that might be taken to preserve and protect these assets, and about the opportunity cost of actions, is highly disaggregated and subject to adverse selection. The adverse selection problem is compounded by the complexity of biodiversity resources; biodiversity is a highly heterogeneous environmental asset. The Victorian Environmental Vegetation framework classifies native vegetation communities into more than 300 major and minor vegetation types, which differ in abundance, distribution and conservation status (DSE 2004). Moral hazard is also a problem because it is difficult and costly to observe and monitor private landholders' compliance with procurement contracts. The moral hazard problem is exacerbated by the highly stochastic nature of environmental production.

Three strategies have been useful in addressing these problems. First, since informational obstacles lie at the root of so many of the difficulties in this area, a systematic attempt has been made to reduce the informational disadvantage as much as possible through the use of appropriate technology and science. The development of new science and technology to address these issues has been fundamental in the development of these schemes. Field ecologists have developed efficient environmental classification and scoring methods (Parkes, Newell & Cheal 2003), and protocols using remote sensing, biophysical models and landscape databases, that allow the classification and valuation of environmental assets with relatively high accuracy and low transaction costs in a single site visit. This ensures that, when procuring biodiversity, the government knows, and can value, what it is purchasing[3]. It also provides a basis for providing information to landholders on potentially valuable actions that government may be willing to purchase[4], and for

[3]It is important to be clear about what is meant by valuation in this context. We assume that the government has a policy with respect to the inventory of environmental assets that it manages, and that government scientists maximise the value of this inventory, according to this policy objective and subject to their budget constraint. We are not concerned with the policy objective or with the optimal size of the agency's budget constraint, but merely with the government's ability to understand and assess what it is buying, and to do so at minimum cost.

To be quite clear, we are not concerned with the demand for environmental public goods but with the efficient supply of such goods. The demand for such public goods is already comprehensively addressed in the literature.

[4]Some information is typically provided on what actions might potentially be purchased, but not on how valuable they might be or on whether there are substitutes.

evaluating the outcome of interventions. Second, adverse selection is addressed by purchasing environmental service contracts through procurement auctions. Bids are ranked according to the environmental benefits they generate and the price of the contract and then accepted or rejected competitively. This process allows government to identify and contract with low-cost suppliers of biodiversity improvements. Finally, moral hazard is addressed by writing incentive contracts contingent on observable actions and outcomes.

This approach has been found to substantially improve the efficiency of government spending (Stoneham et al. 2007). Much better environmental outcomes have been achieved per dollar expended. Because of the emphasis on incentive-compatibility, the interests of landholders and Government are brought much more closely into alignment; in particular, the incentives to reveal private information are much improved, and a number of previously unknown valuable biodiversity assets have been revealed and rehabilitated. Consistent with the incentive-compatible design of the program, there has been wide-spread acceptance of this approach across a range of different interest and stakeholder groups[5].

Building on this successful experience with competitive procurement of environmental services, it is natural to extend it to the procurement of environmental offsets for development. Under the existing "no net loss" regulatory framework, developers are able to destroy existing habitat assets provided that they are granted a permit to do so and that the loss of habitat is offset by the rehabilitation and permanent protection of a commensurate habitat asset. Offsets may be contracted to a third-party supplier of environmental services. Because offsets are underpinned by a stringent regulatory framework, third-party offsets are associated with high transaction costs. Developers must identify an environmentally acceptable offset site, negotiate with potential suppliers on a bilateral basis, design and enter into a contract with suppliers and meet the Government's compliance and administrative requirements. There is also a significant combinatorial allocation problem. Given the heterogeneous nature of habitat assets, one development project may require a package of offsets, and one offset project may contribute to more than one development project. Given the Government's investment in the infrastructure to support efficient environmental procurement, there is an obvious role for government as a facilitator of the market for third-party offsets. A government-facilitated matching market not only reduces transaction costs but improves the environmental integrity of the offset policy. Such a market has recently been announced in Victoria.

There are thus three distinct frameworks for the purchase of environmental assets. The first is the procurement by auction of biodiversity as a public good

[5]Project documentation, reports and evaluations of a number of recent biodiversity procurement auctions are available at http://dse.vic.gov.

by government. The second is the private purchase of environmental off-sets by developers. The third is the facilitation of trade in the off-set market by the government[6] through the procurement of environmental assets on behalf of developers. In each case, the question arises of how to write the contract with the seller of the environmental service. Contract design is important in ensuring that sellers have the incentive to deliver what was agreed, and to do so in the most efficient way. It is also important in convincing government that what is being purchased will be delivered.

2 The model

In considering the issues that arise in biodiversity procurement we will use a version[7] of Laffont and Tirole's basic procurement model (Laffont & Tirole 1986), which we modify to allow for risk aversion[8]. This is a tractable model that is well suited to exploring the issues that arise in biodiversity procurement. It is a useful and flexible procurement model, allowing for both adverse selection and moral hazard, with the advantage that the interaction between contract design and auction design is particularly transparent (Laffont & Tirole 1987). We will follow the notation of their monograph (Laffont & 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 three different policy environments mentioned above. The key parameters will be θ, the weight placed by the principal on the welfare of the agent, and λ, the deadweight cost of raising taxation revenue. For public procurement $\theta = 1$ (since the utilitarian government maximises efficiency) and $\lambda > 0$; for private procurement $\theta = \lambda = 0$, since the principal maximises his own profit; in a government intermediated off-set market $\theta = 1$ but $\lambda = 0$ since the government is concerned with efficiency, and revenue is not raised through coercive taxation. Since we are concerned with optimal contract design we will first consider an environment where a single principal contracts with a single agent. We will discuss below how this case can be modified if there are many agents, and the right to participate is auctioned.

A participating agent can produce environmental output $x + \varepsilon = \beta + e + \varepsilon$, where β is the agent's type, $e \geq 0$ is effort exerted by the agent, and ε is a random

[6] In principle one could imagine a private intermediary playing this role; this seems unlikely due to economies of scale and government's existing role in guaranteeing the integrity of traded off-sets.

[7] We reinterpret effort as output enhancing rather than cost reducing.

[8] See Laffont & Tirole (1986, p. 663) for some general remarks about risk aversion in their model.

shock with mean zero and variance σ^2 reflecting the fact that production is risky (it may also incorporate risk introduced by errors in measuring output). We regard the type β as an endowment of the environmental good, for example a quantity of habitat (measured in quality adjusted units), which can be augmented through the exertion of effort e (for example by improving its quality through the eradication of weeds or feral animals, or protection from fire hazards, or revegetation). Both e and β are private information, known only to the agent, but total output x can be measured (possibly with some error incorporated in ε) by the principal. We assume that the type β is distributed, independently and identically, in the interval $\left[\underline{\beta}, \overline{\beta}\right]$ with distribution function $F(\beta)$ and density function $f(\beta)$ and that the inverse hazard rate $h(\beta) = \frac{1-F(\beta)}{f(\beta)}$ 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 strictly concave (risk averse) in t. For any random transfer z, let $c(z)$ be the cost of risk bearing (the insurance premium that would make the agent indifferent between z and its expected value $\bar{z}$, net of the insurance premium) defined by $Eg(z) = g(\bar{z} - c(z))$. By the separability assumption, we can re-label indifference curves to linearise $g(z)$ (see, for example, Mas-Colell, Whinston & Green (1995, p 45)). We can thus assume that the agent's utility[9], given a random transfer z and an effort level e, is of the form

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

Thus, given this normalisation, the agent's utility depends on the expected transfer, subject to adjustments for a risk premium and for the disutility of effort. Following Laffont and Tirole, we will assume[10] that disutility of effort is increasing and concave 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 $\psi'''(e) \geq 0$.

If the variance is small then the risk premium takes the form

$$c(z) = \frac{1}{2}\eta \operatorname{Var}(z)$$

where η is an appropriate coefficient of risk aversion (Newbery & Stiglitz 1981, pp. 69-80). This relationship holds exactly if z is normally distributed and the underlying utility function $v(t, e)$ displays constant absolute risk aversion with coefficient of risk aversion η; the reader may wish to keep this case in mind[11].

[9]This may no longer be an expected utility functional of z.We note that this type of normalisation is conventional in finance, where a mean-variance specification of preferences is standard. Such preferences are of course not of expected utility form, except in exceptional cases.

[10]The plausibility of these assumptions, which of course depend upon our normalisation linearising $f(t)$, is ultimately an empirical matter.

[11]It also holds exactly if the underlying utility function is quadratic.

In general, it will hold approximately if the variance is small; the appropriate coefficient of risk aversion will then depend upon wealth and background risk (for a recent discussion in the context of a mean variance specification see Franke, Stapleton & Subrahmanyam (2004)). In the interest of tractability we will assume that risk preferences are of this form, and we will ignore wealth effects, due to the contract, on risk preferences. That is, 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 η as a constant. This seems reasonable provided that the agent's risk and return exposure through the contract is not dominant in the agent's portfolio of investments and activities. This seems a reasonable assumption in the policy context with which we are concerned.

The principal offers a menu of linear contracts[12]

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

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 $a\left(\hat{\beta}\right)+b\left(\hat{\beta}\right)(e+\beta)$ and variance $b\left(\hat{\beta}\right)^2\sigma^2$, and achieve utility

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

where

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

is the implied risk adjusted menu of contracts in the agent's decision space. $\tilde{T}\left(x,\hat{\beta}\right)$ is linear in expected outcome (or equivalently effort e). We note that the slopes of the contracts $T\left(x+\varepsilon,\hat{\beta}\right)$ and $\tilde{T}\left(x,\hat{\beta}\right)$ are the same, but that the intercept of $\tilde{T}\left(x,\hat{\beta}\right)$ is adjusted by an amount that depends on both $a\left(\hat{\beta}\right)$ and $b\left(\hat{\beta}\right)$ to

[12] In contradistinction to (Laffont & Tirole 1986), we restrict ourselves to linear contracts in order to accommodate risk aversion.

accommodate the cost of risk bearing. We notice[13] that, irrespective of $\hat{\beta}$, the optimal effort level e does not depend on the variance σ^2.

We write

$$u(\beta) = \max_{\hat{\beta},e} U\left(\hat{\beta}, e, \beta\right)$$

for the information rent earned by an agent of type β. 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

$$\begin{aligned}
t(\beta) &= \mathrm{E}\, T(x(\beta) + \varepsilon, \beta) \\
&= T(x(\beta), \beta) \\
&= a(\beta) + b(\beta)\, x(\beta) \\
\tilde{t}(\beta) &= \tilde{T}(x(\beta), \beta) \\
&= a(\beta) + b(\beta)\, x(\beta) - \frac{1}{2}\eta b(\beta)^2 \sigma^2 \\
&= t(\beta) - \frac{1}{2}\eta b(\beta)^2 \sigma^2
\end{aligned}$$

for the expected transfer and the risk adjusted expected transfer respectively. To reduce notation we will when convenient drop the argument β 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 β by a dot. If the principal offers an incentive compatible individually rational contract, then by standard arguments we have

$$\begin{aligned}
u &= \tilde{t} - \psi(e) \\
x &= e + \beta \\
\tilde{t} &= t - \frac{1}{2}\eta\sigma^2\psi'(e)^2 \\
\dot{u} &= \psi'(e) \\
b &= \psi'(e) \\
\dot{\tilde{t}} &= \psi'(e)\, \dot{x} \\
\dot{x} &\geq 0 \\
u(\underline{\beta}) &= 0
\end{aligned}$$

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. As

[13] This is because of the additive specification of the error ε and our assumption that, for wealth variations implied by the contract, η is constant.

β varies the contract $\left(x\left(\beta\right),\tilde{t}\left(\beta\right)\right)$ traces out a locus, the contract curve, in agent's $\left(x,\tilde{t}\right)$ space. The slope of the contract curve is $\frac{d\tilde{t}}{dx}=\frac{\dot{\tilde{t}}}{\dot{x}}=\psi'\left(e\right)$. This contract curve is the envelope of the menu of linear contracts $\tilde{T}\left(x,\hat{\beta}\right)$.

The principal chooses the contract (x,t) (and hence implicitly e and u), subject to incentive compatibility and individual rationality constraints, to maximise the objective

$$\max_{\{x(\cdot),u(\cdot)\}}\int_a^b\{x-(1+\lambda)\,t+\theta u\}\,dF$$

where λ 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, making use of the envelope condition and the individual rationality constraint, the principal's problem becomes

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

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

By a standard argument the integrand is concave in e, and the optimal effort is determined at interior points by the principal's first order condition

$$1=(1+\lambda)\,\psi'\left(e\right)\left(1+\eta\sigma^2\psi'\left(e\right)\psi''\left(e\right)\right)+(1+\lambda-\theta)\,h\psi''\left(e\right).$$

It can then be shown that the contract curve is convex in $\left(x,\tilde{t}\right)$ space, confirming that the contract may be implemented by a menu of linear contracts, tangent to the contract curve.

We now consider the case of multiple agents. Under risk neutrality contract design is particularly simple Laffont & Tirole (1987). If there are multiple agents the interaction between contract design and a preliminary auction is particularly simple. The optimal mechanism can be implemented by conducting a preliminary auction[14] of the right to participate, and then offering exactly the menu of contracts derived above for the single agent case. The effect of the entry fee, as determined by the auction, is to contract the type space of the participating agents to $\left[\beta_0,\overline{\beta}\right]$,

[14] If one object is to be purchased than a second price auction is appropriate. If multiple objects are to be purchased, as in our context, then a uniform price second price auction is appropriate.

where β_0 is the type of the highest non-participating agent. Thus competition between agents reduces, but does not entirely eliminate, uncertainty about the agents' types. 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 is not straight forward, except in one case that we will focus on. If the cost of effort function $\psi(e)$ is quadratic[15] (this includes the case of constant marginal effort) and we write

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

for the total cost including risk bearing, then the Hamiltonian (1) can be written

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

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 $\frac{h}{(1+\delta\eta\sigma^2)}$. Laffont and Tirole's proofs then go through exactly as before, so we get the basic separability result. Thus in this quadratic cost case the optimal mechanism can be implemented by a preliminary auction of the right to participate, and then by allowing participants to choose a contract from the menu derived above exactly as in the single agent case. In particular, 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 β is distributed uniformly on the interval $\left[\underline{\beta}, \overline{\beta}\right]$, so $h(\beta) = \left(\beta - \underline{\beta}\right) / \left(\overline{\beta} - \underline{\beta}\right)$, and that $\psi(e) = \frac{e^2}{2}$. For simplicity, we will assume that $\left[\underline{\beta}, \overline{\beta}\right] = [0,1]$. In this case the principal's first order condition is

$$1 = (1+\lambda-\theta)(1-\beta) + (1+\lambda)\left(1+\eta\sigma^2\right)e$$

so the contractual level of effort is

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

The principal's virtual surplus (the expression in the integrand (1)) is

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

[15] This is clearly a restrictive assumption, but not unreasonable as a first approximation.

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 $k(\beta)$ is non negative over the whole interval $[0,1]$, and u can be calculated by integrating $\dot{u} = \psi'(e)$ from zero, yielding

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

In general, the virtual surplus will not be non-negative over the whole interval. There will be some cut-off type β_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 β_0. The transfers t and $\tilde{t}$ are readily calculated from e and u.

3.1 Policy settings

We show in Figures 1 and 2 the behaviour of variables of interest for typical parameters, using the example calculated above. In these Figures we have allowed the type space to be more general than the $[0,1]$ used for simplicity above. In fact we have set $[\underline{\beta}, \overline{\beta}] = [-1, 0.5]$, to illustrate the scenario where many landholders will own a significantly degraded asset which would, without any remedial effort, have a negative value as an environmental off-set, while some may hold assets of considerable value. These Figures also illustrate that there is a critical cut-off type, and types below this would not participate.

We consider, as above, three policy settings. The first is government procurement. The government is efficiency maximising, putting equal weight on the utility of the principal (the tax payer) and the agent, so $\theta = 1$, but raises revenue through distortionary taxation, so $\lambda > 0$. In this example, we have put $\lambda = .2$. This policy setting is shown with a dashed line. The second setting is private procurement of environmental offsets. In this case, we have assumed that the principal (the developer) is a monopsonistic[16] purchaser, facing no funding distortion, and placing no weight on the utility of the agent, so we set $\lambda = \theta = 0$. This case is shown with a solid line. In the third case the government, acting as an intermediary in the off-set market, procures off-sets and sells them on to developers. We assume that the government is benevolent, placing equal weight on both parties (so we implicitly assume that the government acts to correct the monopsony distortion, maximising total social surplus rather than just the monopsonist's share). Since the off-set is paid for by the developer, there is no funding distortion, and we set $\theta = 1$, $\lambda = 0$. This case is shown with a dotted line. Figure 1 shows effort, output, transfer

[16] This means that they can unilaterally design the contract, as is usually assumed in principal-agent problems.

and the agent's information rent by type. Figure 2 shows the optimal contract. This may be represented as a nonlinear contract in either observable $(x+\varepsilon, t)$ output-transfer space, or in the agent's (e, u) effort-utility decision space.

We also show, in the final panel of Figure 2, the menu of linear contracts that implements the optimal contract. A linear contract is a contract of the form $t = a + bx$, promising a fixed up-front payment a, and a conditional payment bx that depends upon the output achieved. Since typically $0 \leq b \leq 1$, this takes the form of a surplus sharing rule. For example, if $a = 3$ and $b = .5$, then the contract would specify an up front payment of 3 plus 50% of the value of the output generated. By offering a menu of such contracts $t = a(\beta) + b(\beta)x$, one for each type β, the agent can choose either a soft contract (with a low b and a weak incentive to maximise output) or a tough contract (with a high b and a strong incentive to maximise output). The agent who chooses the tough contract will be rewarded with a higher up front payment a. By the revelation principal, each agent will choose the contract appropriate to their type. By choosing this contract, they are in effect induced to reveal their private information, and optimal effort is induced.

It may happen that the up front payment is negative. In this case, it is convenient to specify the linear contract as an output target and a marginal payment, rather than an up front payment and a marginal payment. For example if $a = -1$ and $b = .5$, then the contract $t = -1 + .5x$ can be written equivalently $t = .5(x-1)$ which can be interpreted to say that the agent gets nothing until they reach an output target (of 1 in this case), and then they get 50% of the value of the output beyond this target that they produce. In the third panel of Figure 2 we have chosen to present the menu of contracts in this form, as a locus of pairs (x_0, b) where x_0 is an output target and b is an output value share. Clearly a negative output share can be reinterpreted as a positive up front payment, just as a negative up front payment can be interpreted as an output target.

It is clear from these Figures that the optimal contract is quite different in each policy setting. The offset market contract is particularly simple and it is easy to see why this should be so, especially if agents are risk neutral. In this case, the government wants to maximise total surplus and does not care how it is allocated. In particular, it is happy for the agent to retain all the surplus (this surplus may be extracted 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 pooling contract inducing the first best effort level. If the agents are risk averse then it is no longer optimal for them to bear all the risk, but since risk aversion is unrelated to type under our assumptions it is not useful to screen agents by exposure to risk, and a simple pooling contract is still optimal.

In this policy setting the same contact is offered to everyone.

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 strongly, inducing a wide variation in effort levels. The government procurement contract is in some ways intermediate between the two. The government has an incentive to minimise transfers to the agent because of the distortionary cost of raising revenue ($\lambda = .2$). It also implements a screening contract, but one that screens less aggressively than that the private developer.

The contracts, as actually implemented, have a rather different style to them (the details here are sensitive to the parameters chosen). When procuring for the off-set market, the government offers a simple take it or leave it contract (not a menu), characterised by an up front payment and a relatively high performance incentive. The developer offers a wide range of linear contracts, characterised by an output target and a range of performance incentives, some of them quite weak. When procuring to augment the stock of public goods, government offers a menu of contracts that is intermediate between the two. With the parameters chosen here, the high power contracts are characterised by an output target, while the low power contracts are characterised by an up front payment.

4 Discussion

Market based instruments for biodiversity procurement, either to enhance the stock of assets or to facilitate trade in off-set markets are increasingly important. Standard procurement models can be adapted to provide a workable framework for contract design in such markets. What do we learn from this modelling exercise?

First of all, it is not the case that contract design can be treated as a discrete problem without considering the policy environment. Contracting frameworks that make sense in one environment cannot necessarily be applied without thought to another, despite the apparent similarity of the problems.

In the case of biodiversity regulation and procurement, we find that contract design is simplest for the case of off-set markets. In this case there is no need to screen agents through the contracting framework, and a simple off-the-shelf linear contract will do to job. This simple contract will have two components: a fixed component a (which may be either positive or negative) and a variable component b. Participation is then determined by an auction, in which landholders compete to bid down the size of the payment t that they would be paid in order to sign a contract. The net immediate payment, on signing of the contract, is $a + t$. The variable payment, received at the end of the contract, depends on the outcome. b is the proportion of the value created that goes to the landholder.

In practice, the fixed component may various forms. It may be an up-front cash payment, paid when the contract is signed. This payment might be negative - it would then be a participation fee, paid by the landowner when the contract is signed. It might be an agreed target outcome level, which must be reached before any payments under the variable component are made. It might be a package of easily verifiable actions and payments that can be carried out when the contract is signed, or in some initial phase. In practice, biodiversity procurement contracts usually specify some payments against the verifiable provision of various inputs (for example, erecting fences). In our framework such payments for immediate verifiable inputs would be part of the fixed component of the contract. There is clearly considerable freedom in putting together the fixed component bundle a; we would expect the equilibrium bid t to adjust so as to keep $a + t$ constant.

The variable component of the contract, in the case of an off-set market, is likely to be quite steep. If agents are risk neutral, then at the margin they should be paid the full social value of the increment in environmental services that they provide (that is to say, $b = 1$ and they would be paid the full value of any output that they produce beyond any contractually agreed target threshold). If agents are risk averse, then they must be compensated to some degree for bearing risk: stochastic production risk and measurement risk, and we would expect this cost to be built into their initial bid. If agents are risk averse it is optimal to moderate the variable component of the contract to introduce some risk sharing. Landholders might receive, for example, 60 per cent of the value of output beyond the agreed threshold. The slope of the contract will depend on the amount of risk (both production risk and measurement risk) and on the degree of risk aversion; the higher these are, the higher is the cost of risk bearing, and the flatter (softer) will be the optimal contract. Naturally, any actions that can be taken to reduce exposure to risk will lead to more favourable (and 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 is also likely to be very important.

Optimal contracts for procurement markets will differ from those in an off-set market. In this case it is optimal to screen bidders, inducing them to reveal information about their private characteristics by the type of contract that they choose, and reducing the information rents that are paid to them. The incentive to screen is stronger for private procurement than for public procurement, and the private procurer will offer a relatively wider range of contracts, including some that are quite aggressive and will appeal only to high types, and some of lower power. Such screening reduces information rents and the payment to agents, but potentially induces lower effort levels. The public procurer will screen less aggressively, offering a menu of contracts intermediate in structure between the private procurer and the off-set market contract.

Contract design is thus sensitive to the institutional framework. In contrast, at least within the theoretical framework[17] used here, it is not sensitive to the number of bidders. This means that contract design does not need to differ according to the intensity of competition; competition 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.

The model that we have used here, based on the Laffont & Tirole (1986) procurement model, is tractable, convenient and flexible, and leads to useful insights into the nature of the contract design problem for biodiversity procurement. It would be good to know how robust these conclusions are to relaxing the assumptions embedded in this specification. It is unlikely that closed form solutions can be found, and numerical simulation would be required. Before doing so, empirical evidence on the validity of these assumptions would be valuable. More generally, it would be valuable to understand the empirical inputs required for contract design. The key empirical inputs are the degree of risk aversion, the distribution of types in the population, and the shape of the effort curve (and more generally the nature of the biodiversity production function and the monitoring technology). As is usual in the application of theory to policy, the main contribution of the framework is probably its value in organising concepts and ideas. However some basis for empirical judgements exists, and any contract design put forward in practice implicitly takes a position on these empirical questions.

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 (see for example Paarsch & Hong (2006)). Analysis of these datasets could provide very valuable information. Getting information on the effort function and the production function for environmental goods may require a different approach. Biological and biophysical modelling and simulation is widely used to model agricultural systems, and may be able to be adapted to model the production of habitat and biodiversity assets. Direct experimentation may also be possible. It may be valuable to design future procurement programs to facilitate the estimation of such relationships, and the testing of the hypotheses underlying the standard contracting framework.

[17]Most importantly, the separability of effort in the utility function and the quadratric effort function.

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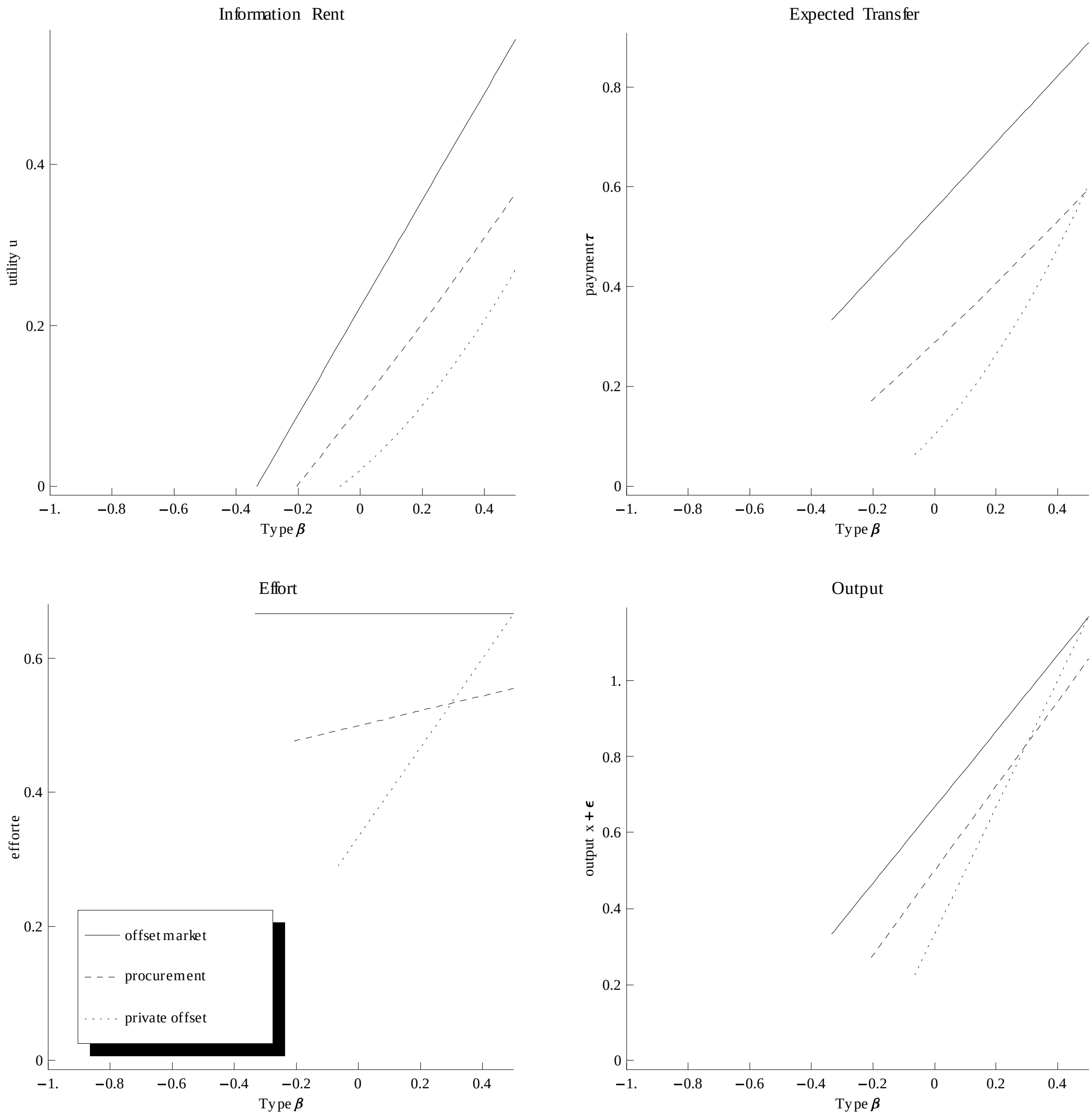

Figure 1: Effort, outcomes, and transfers to type β.

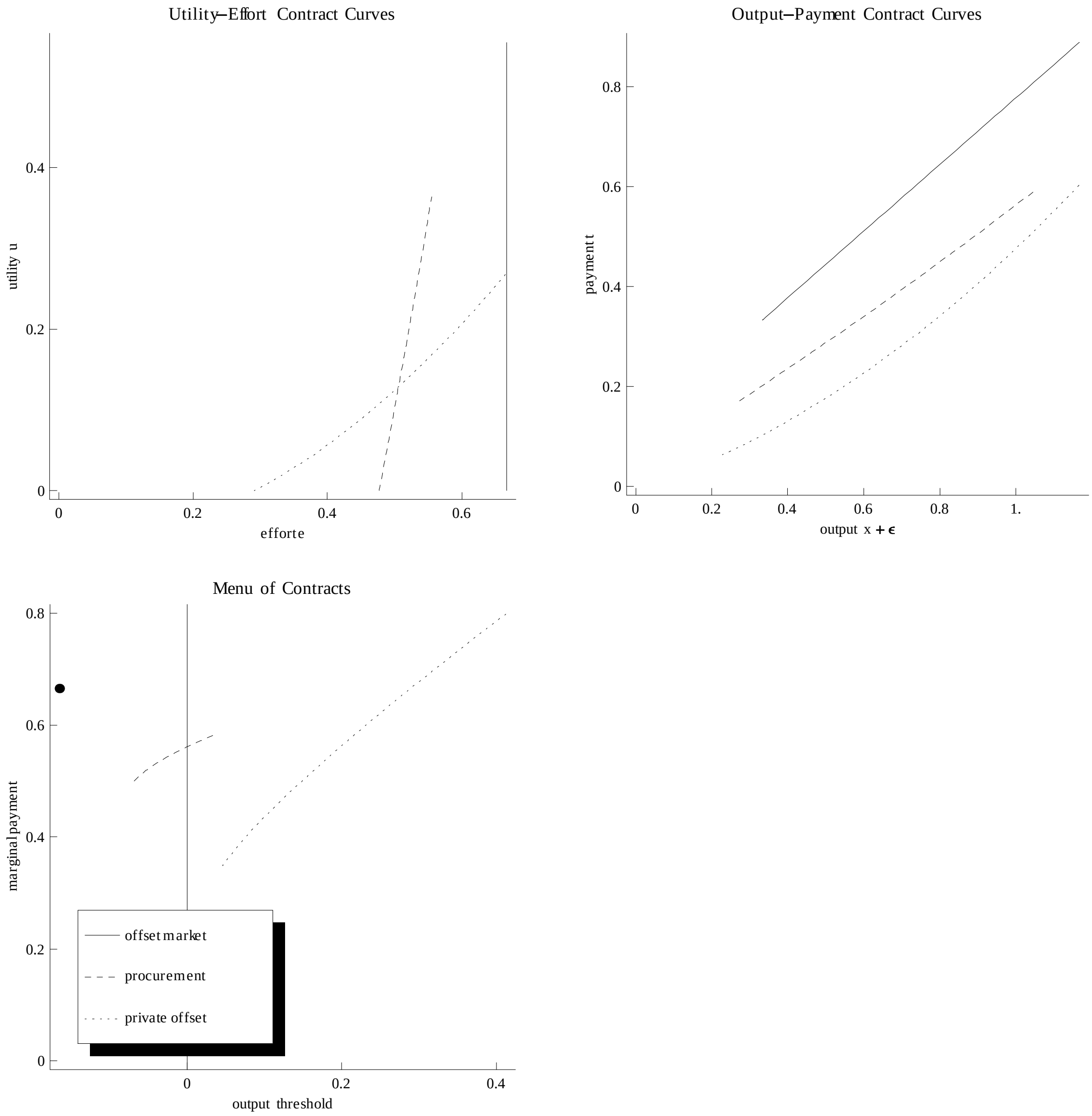

Figure 2: Optimal Contracts