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Auctions for conservation contracts: an empirical examination of Victoria's BushTender trial*

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The present paper proposes that markets for nature conservation on private land are missing because of the problem of asymmetric information. An auction of conservation contracts was designed to reveal hidden information needed to facilitate meaningful transactions between landholders and government. The present paper describes the key elements of auction and contract design employed and the results obtained from a pilot auction of conservation contracts run in two regions of Victoria. The pilot demonstrated that it was possible to create at least the supply side of a market for nature conservation and in conjunction with a defined budget, prices were discovered and resources allocated through contracts with landholders. The present paper compares a discriminative price auction with a hypothetical fixed-price scheme showing that an auction could offer large cost savings to governments interested in nature conservation on private land. The paper identifies some important design problems that would need to be solved before auctions could be applied more broadly including: multiple complementary outcomes, reserve prices, sequential auction design and contract design. Nevertheless, the paper does show that auctioning conservation contracts for environmental outcomes is an important new policy mechanism that deserves closer examination.

1. Introduction

A century ago in Australia food and fibre were scarce relative to the supply of habitat. Today the opposite could be argued. Governments now face the

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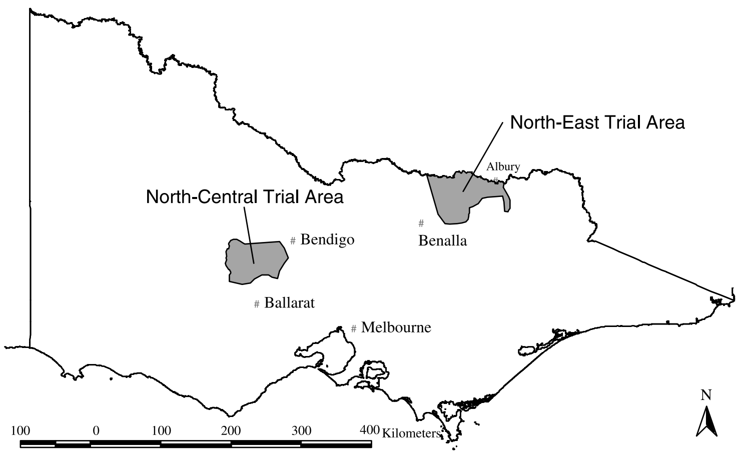

Figure 1 Location of the pilot auction of conservation contracts.

problem of encouraging landholders to provide public goods, such as habitat conservation, in the face of an economic environment that facilitates the production of private goods.

Governments, both in Australia and overseas, have used a wide range of policy mechanisms to influence private land management including fixed-price grants, tax incentives, voluntary schemes, and so on, Latacz-Lohmann and Van der Hamsvoort (1997) propose, however, that auctioning conservation contracts as a means of creating markets for public goods has many theoretical advantages. They argue that competitive bidding, compared with fixed-rate payments, can significantly increase the cost effectiveness of conservation contracting because of the cost revelation advantages of bidding processes.

The present paper examines the performance of an auction of nature conservation contracts conducted in the North-east and North Central regions of Victoria (figure 1). Run as a pilot, this auction differs from existing conservation programs in Australia, the USA and the UK in that it was specifically designed for nature conservation purposes, drawing on the now extensive published auction and contract design literature and incorporating new approaches to measuring habitat quality. Following a brief discussion of nature conservation programs that have been implemented in Australia and overseas, the present paper draws on the published auction design literature to identify the key elements of an auction of nature conservation contracts. Results and a discussion of the implications of this approach are presented in the final sections.

2. Conservation of biodiversity on private land

In Victoria there is over one million hectares of native vegetation remaining on private land. Much of it is of high conservation significance providing habitat for native plants and animals as well as generating other environmental services. Approximately 15 per cent of Victoria's threatened vegetation types rely solely on private land for their survival. An additional 29 per cent of threatened vegetation types occur largely on private land, making private land conservation an imperative if these species are to be conserved (Stoneham *et al.* 2000). Conserving biodiversity on private land has been an important, but elusive, objective for government agencies. Generally, it has not been feasible to include remnant vegetation on private land in the national reserve system. This is because remnants are often of small scale and are spatially dispersed so that incorporating them into the reserve system would involve high maintenance and protection costs and would not take advantage of local knowledge, expertise and resources. Fitzsimons and Wescott (2001, p. 142) argue that public reservation is unlikely to be successful from a biodiversity point of view anyhow stating: 'it is … increasingly recognised that strict reservation alone will not conserve all, or even most, biodiversity', and that 'effective "off-reserve" conservation measures are needed to ensure the effective conservation of species, communities and ecosystems'.

Despite government programs, many important biodiversity assets on private land remain subject to degradation because of land-use practices such as livestock grazing, firewood collection and weed and pest invasion. NRE (2000, p. 32) concluded that the existing programs employed to achieve biodiversity conservation objectives have 'failed to engage landholders, particularly commercially orientated farms'.

2.1 Nature conservation programs

Both state and commonwealth governments allocate large budgets to environmental and natural resource management. The Natural Heritage Trust annual report 2000–01 shows that this program will have committed approximately $A2.5 billion to environmental works by June 2007. A further $A1.4 billion has been allocated to The National Action Plan for Salinity and Water Quality over a seven year period by state and federal governments (Australian National Audit Office 2001). These and other environmental and natural resource management programs employ a combination of intervention mechanisms including community and catchment-based planning, voluntary programs, fixed-price subsidies and grants, education programs and capital works programs.

Although there is general acknowledgement that these programs have altered community awareness about environmental issues, there is not a widespread belief that they have cost-effectively achieved significant on-ground outcomes. For example, the Australian National Audit Office (2001, p. 90) commented on the Natural Heritage Trust by saying that the program has been successful in 'raising awareness and empowering communities … good in fostering integrated planning … but few [projects] have the potential to lead to broad scale long term landscape outcomes, poor in monitoring and accounting for performance, poor in administration and cost shifting by States and Territory governments'. So, while achieving attitudinal shift, these programs have been less effective at delivering and demonstrating improvements in the environment.

State governments have legislative responsibility for private land. Legislation controlling clearing of native vegetation, such as The Planning and Environment Act in Victoria, is used in most states. In South Australia, this legislation is linked with other programs (Heritage Agreements) which offer, but do not guarantee, access to financial assistance where landholders are denied approval to clear (Denys Slee and Associates 1998). Assistance for fencing of remnants, weed and vermin control is available in Western Australia, New South Wales and South Australia (Denys Slee and Associates 1998). These programs generally offer differential rates of assistance depending on the level of commitment by landholders. State governments sometimes make targeted purchases of land to address critical gaps in the reserve system and revegetation programs operate through grants to community groups. These programs are often supported by federal funding programs such as Bushcare and Landcare. A range of voluntary programs are supported by state governments. Land for Wildlife, for example aims to establish non-binding agreements with landholders for land managed for biodiveristy conservation in Victoria (Stoneham *et al.* 2000). The states, or state-based organisations also offer programs such as the Voluntary Conservation Agreement Program in Queensland and Conservation Agreements (Trust For Nature) in Victoria (Denys Slee and Associates 1998). These schemes are legally binding and often have offsetting concessions such as rate relief, cash offsets or fencing concessions.

In other countries, environmental agencies have implemented a number of policy mechanisms to deal with nature conservation on private land. The USA has employed essentially two approaches: farmland protection easements and mechanisms that involve payments to landholders. The latter includes the Conservation Reserve Program (CRP) and the Wetlands Reserve Program (WRP) which are funded under the US Farm Bill. These programs evolved partly from concerns over soil erosion and partly from assistance programs for farmers. Predecessors to the CRP, such as the Soil

Bank Program, were introduced to divert land from crop production in order to reduce commodity inventories as well as to establish protective cover for land taken out of production (see Wiebe *et al*. 1996). The CRP commenced in 1985 with broad environmental objectives and with a requirement that funds be allocated on a competitive basis. Currently, farmers bid for public funds based on an environmental benefits index (EBI) – this scores landholders based on six environmental factors (wildlife, water quality, erosion, enduring benefits, air quality, conservation priority areas) and a cost factor. The US Department of Agriculture (USDA) selects contracts based on the EBI, but it has a reserve price based on the rental value of land adjusted for its productive capability. Other programs, such as the USDA Water Quality Incentive Program (WQIP), involve stewardship payments and the provision of technical information about surface and groundwater management. The WQIP uses fixed payments to landholders (Cooper 1997).

In Canada a Permanent Cover Program (PCP) has been introduced to encourage soil conservation and other environmental outcomes on farmland. The PCP employs a fixed payment approach with participating landholders required to engage in long-term contracts (including a buy-out option). Payments are determined on the basis of the length of the contract and the area involved.

Fraser and Russell (1997, p. 71) provide an overview of agri-environmental schemes in the UK, three of which are relevant to nature conservation on private land: Environmentally Sensitive Areas (ESA); the Conservation Stewardship Scheme (CSS); and the Nitrate Sensitive Areas (NSA). The ESA and the NSA target farmers in specific geographical areas. The ESA focuses on the 'maintenance or enhancement of the environmental and landscape quality' and the NSA focus is on reducing the presence of nitrates in water. Both schemes offer fixed payments for undertaking certain actions.

Wynn (2002, p. 836) analysed the ESA scheme in Scotland and found that it did not target farms with high biodiversity, nor focus on low-cost producers. Wynn notes that 'targeting least-cost managers would increase the cost-effectiveness of the scheme, and could be introduced under market or auction delivery mechanisms'.

The CSS targets environmental features, not geographical areas. The CSS offers a fixed payment for prespecified actions, however, not all farmers who submit an offer are accepted. Instead, the CSS agency chooses farmers who offer the best quality management plans.

3. The economics of nature conservation on private land

It is widely acknowledged that existing markets and institutions misallocate resources to environmental goods and services. Several explanations have been given for why this is the case. Standard economic textbooks use the explanation that externalities and public goods result in misalinged incentives between private players and society – a market failure that results in an inefficient outcome. However, sometimes market failure is attributed to the more generic reason of transaction costs. This follows from the seminal article by Coase (1960) where he argues that a clear delineation of property rights would allow private agents to bargain to an efficient solution. This so called 'Coase Theorem' is based on the premise that transaction costs are zero, and that information is complete. However, even if property rights are well defined, transaction costs may inhibit non-zero exchange.

Transaction costs take many forms. Williamson (1996, p. 379) defines transaction costs as the '*ex ante* costs of drafting, negotiating, and safeguarding an agreement and more especially, the *ex post* costs of maladaptation and adjustment that arise when contract execution is misalinged as a result of gaps, errors, omissions, and unanticipated disturbances'. On some occasions, information asymmetries are subsumed into the umbrella of transaction costs. For example, Williamson (1985) has used the term 'information-impactedness' to describe any situation where there is incomplete, or asymmetric information. Williamson argues that information impactedness affects the feasible modes of organisation (or contract). Generally, information impactedness increases the cost of a transaction, hence, parties to a transaction will attempt to minimise these costs through contract design, or governance arrangements.

In contrast, McKelvey and Page (2000) argue that asymmetric information is not a subset of transaction costs. However, they still argue that asymmetric information can also lead to inefficient bargains between players – a breakdown of the Coase Theorem.

The basic idea that information asymmetry affects the way markets operate was introduced by Akerlof (1970). Subsequently, many economists have refined our understanding of how the distribution of information affects market players, and how these players may or may not respond to the problem (e.g., see Laffont 1990). The published literature on information economics has forced economists and policy makers alike to reassess policy mechanisms employed for many public policy problems. Likewise, there are new insights into policy mechanism design that arise from the application of information economics to environmental problems. Latacz-Lohmann and Van der Hamsvoort (1997, p. 407) explain how information asymmetry affects the functioning of markets for environmental goods and services associated with private land. They note that there is a 'clear presence of information asymmetry in that farmers know better than the program administrator about how participation (in conservation actions) would affect their production plans and profit'. Likewise, environmental experts, not landholders, hold information about the significance of environmental assets that exist on farm land. Further, landholders may not have all the relevant information about government priorities and are unlikely to understand how this information might influence subsequent contracts. Hence, although flat-rate Pigouvian taxes and subsidies may 'correct' market failures in circumstances where information asymmetry is not evident, other policy mechanisms will be needed when information is hidden. Latacz-Lohmann and Van der Hamsvoort (1998, pp. 334–335) conclude 'that some institution other than a conventional market is needed to stimulate the provision of public goods from agriculture'. They argue that auctions are 'the main quasi-market institution used in other sectors of the economy to arrange the provision of public-type goods by private enterprises'.

Auctioning conservation contracts is therefore a means of creating missing markets for nature conservation. The basic proposition is that markets for nature conservation are missing because of the asymmetric information problem and that policy mechanisms can be designed to reveal hidden information needed to develop meaningful contracts between government and landholders. It is contended that this process will facilitate price discovery and allow resources to be allocated where this has been difficult and inefficient in the past. The following sections draw on published auction and contract design literature to identify the key features of this approach.

3.1 Auction design

Formal analysis of auctions in the published economic literature is relatively new. While a complete literature review on the many design aspects of auctions is beyond the scope of the present paper, a broad understanding of the underpinnings of current theory is instructive. Early work on auctions stems from the seminal papers of Friedman (1956) for the case of a single strategic bidder, and Vickrey (1961) for the equilibrium game theoretic approach. The development of appropriate game theoretic tools has made auction theory an increasingly researched topic. The three broad models studied are: the independent private value model of Vickrey (1961), the symmetric common value model of Rothkopf (1969) and Wilson (1969, 1977), and the asymmetric common value model of Wilson (1967). Several survey articles summarise the published auction design literature (see McAfee and McMillan (1987), Wolfstetter (1996), and Klemperer (2002)). Latacz-Lohmann and Van der Hamsvoort (1997) apply this literature to identify the key features of an auction of conservation contracts.

The possibility of collusion between landholders bidding in an auction is always an important consideration in the choice of auction format. Repeated open, ascending and uniform-price auctions are generally more susceptible to collusion than a sealed-bid approach (see Klemperer 2002). Moreover, where bidders are risk-averse, as we might well expect with private landholders, a first-price sealed bid auction will facilitate lower bids because landholders can reduce commodity and weather related income variability by adding a regular income stream from conservation payments (Riley and Samuelson 1981).

Latacz-Lohmann and Van der Hamsvoort (1997) note that a single round of bidding is preferred to multiple rounds because landholders are assumed to have independent private values rather than common values. In a private values model, each agent knows their own valuations with certainty but makes predictions on the values of others, while in the common values world, players have identical valuations but form their estimate on the basis of private information. In a common values world, agents will be able to learn about the 'common value' of the asset through the bidding strategies of all the other agents (as each agent has private information on the value of the asset). Thus, multiple rounds of bidding can facilitate information aggregation in the market and enable bidders to get a better sense of the true (common) value of the asset. This can help to mitigate the 'winner's curse' – the situation where an item is allocated to the most optimistic bidder (i.e., the bidder with the highest valuation), rather than the bidder whose valuation is closest to the true valuation. However, where values are private and specific to each individual, information aggregation does not yield superior outcomes. Variation from farm to farm with respect to soil quality, rainfall, production systems etc. suggests that each landholder would base their bid on private, rather than common information about opportunity costs and would be unlikely to alter this bid when given information about other landholders' valuations.

Where bidders draw valuations from different distribution functions, Myerson (1981) argues that optimal auction design is achieved by assigning contracts to the lowest bidders. Note that the performance of the auction format can be thought of from two perspectives. First, as in the Myerson (1981) case, which format maximises the value created and second, how does the auction divide value between the buyer and the suppliers? These questions lead to consideration of whether a one-price or price discriminating auction should be employed. Though the theory on optimal bidding strategies in a discriminatory price auction versus a one-price auction is inconclusive, it is worth noting that in the event that both formats are successful in achieving truthful revelation, a discriminatory price auction is analogous to a first degree price-discriminating monopolist. As such, there will be a change in the distribution of value, not the quantum of value created. Similarly, in the context of an auction of nature conservation contracts, the discriminatory price auction would, subject to the caveat highlighted above, achieve the same outcome as the one-price approach, but at lower cost. However, because of asymmetric information, the ranking of bids may change because the bids of agents in an auction may include information rents (see section 3.3 for a technical exposition) whereas agents in a one-price scheme will enter bids based on opportunity cost.

Cason *et al.* (2003) used laboratory experiments to examine bidder behaviour in an auction when the value of their output was known, compared with when it was not. These experiments indicate that when bidders did not know the value of output, their bids tended to be based on the opportunity costs of land-use change. By contrast, when bidders were given information about the significance of their biodiversity assets, they tend to raise bids and appropriate some information rents.

A reserve price strategy is a key element of auction design. However, reserve prices are less important where there is a budget constraint (see Myerson 1981; Riley and Samuelson 1981). In the case of nature conservation contracts, a reserve price would be a price 'cap' on what bids the agency is willing to accept. However, in repeated auctions, a reserve price strategy would become more important. In a repeated auctions situation it would be possible to transfer funds between rounds of auctions to maximise the nature conservation outcomes presented in other regions, or in subsequent auctions. In particular, an appropriately designed reserve price would have implications for intertemporal resource allocation, from both the state's, and farmers' perspective.

In summary, the key design elements relevant to auctioning nature conservation contracts to private landholders include: first-price, sealed bid, single round, price minimising and price discriminating format. A severe budget constraint applied to the auction and a reserve price was not formulated a priori. In the pilot auction, the exact value of the landholder's biodiversity asset was withheld from the landholder to improve the auction's cost-effectiveness. There are, however, other considerations that may influence this strategy. These are discussed later in the present paper (see section 6). This auction differs from the CRP (the only other comparable policy mechanism involving competitive bidding for nature conservation contracts) in that it was designed explicitly to allocate public funds to nature conservation on private land rather than the allocation of business assistance. It differs from fixed price and voluntary schemes by requiring landholders to implicitly reveal private cost information.

3.2 Contract design

There are many design issues that arise in the development of contracts between government (the principal) and landholders (agent) to conserve biodiversity on private land. From contract theory, the main problems of contract design relate to incentives and asymmetric information. Specifically these problems are manifested as adverse selection, moral hazard and observability. Other problems of contract design include commitment, credibility and incomplete contracts (Salanie 1997).

Adverse selection refers to situations where agents have private information on their types (e.g., information on costs) that would be valuable to the principal in terms of contract design. In the case of nature conservation contracts, the opportunity cost of land-use is hidden from the principal but will be important in the selection of successful contracts and in the price associated with conservation services offered. The problem with adverse selection here is the payment of information rents to induce the agent to reveal private information (Salanie 1997).

Moral hazard refers to the problem of agents hiding their actions. It leads to consideration of contracts that mitigate against agents 'shirking' their commitments (Laffont and Martimort 2002). Even if contracts can be designed to prevent adverse selection and moral hazard, outcomes may still be un-observable. Observability has implications for monitoring and enforcement of contracts and their subsequent incentive effects on agents' behaviour (Laffont and Martimort 2002). Observability is a problem with nature conservation contracts because it is difficult to measure and monitor the status and resilience of habitat for native plants and animals. For example, monitoring the impact of changes to land management in terms of the improvement in the stock and quality of fauna and flora would be very costly and subject to dispute. An alternative strategy would be to specify a contract on the basis of inputs that can be expected to improve habitat quality, such as fencing, weed control, understorey protection etc. These inputs are known to improve habitat status and resilience, but the transformation function that maps these actions (inputs) into outcomes is not known with certainty, even if the actions were carried out diligently. Further, the effect of unexpected events, such as drought and floods, could not reasonably be predicted by the agent (landholder), nor the principal (government).

These two problems (unobservability of outcomes and imperfect knowledge about the transformation function) were considered by Ouchi (1979), and explained in the context of the public sector by Wilson (1989). Williamson (1985) has characterised this as the problem of 'measurement'. The published principal-agent literature has considered one or both of these problems to varying degrees (e.g., see, Holmstrom and Milgrom 1991, 1994). This literature has recommended a host of ways to deal with these difficult problems, including organising activities inside the firm, using fixed pay arrangements (again inside the firm), and contracting on the basis of inputs.

Conservation contracts for the pilot were developed based on inputs rather than outcomes. This was because there were no low-cost means of measuring outcomes on which to base (enforce) these contracts. Because environmental benefits vary from site to site (non-standard benefits), individual management agreements specifying a schedule of management commitments were employed with progress payments made on the basis of inputs. This allowed the government scope to identify what actions were valuable, from a nature conservation perspective, and for landholders to choose from a menu of actions that they preferred. For example, on some sites regenerating understorey was an imperative, whereas on others agreeing not to collect firewood (this action disturbs habitat) was relatively important. Contracts extending over three years were developed with approximately one-third of participants monitored each year. This provided government with a simple sanction in the case of non-performance; that is, funds can be withheld or withdrawn.

This type of contract has implications for risk bearing. Specifically, the government agency bears most of the risk associated with structural parameters where contracts are specified in terms of inputs. This was considered sufficient for the pilot, where the main purpose was to test the auction mechanism and the supporting information systems. However, improvements in knowledge (for example, new technology that allows lower cost monitoring of species prevalence) may enable a government agency to base at least part of its payments on output.

3.3 A bidding model for nature conservation on private land

It is possible to represent an auction for nature conservation contracts as a model of optimal bidding behaviour. In this model, an agency such as the government, wishes to purchase remnant vegetation using a first-price sealed bid auction from N landholders (indexed by $i = 1, 2, 3, \ldots, N$). The government purchases remnant vegetation from private landholders based on three factors:

1. The biodiversity significance of remnant vegetation – Landscapes that have been modified for agricultural purposes will not necessarily retain a representative mix of habitat types. One way of expressing the conservation value of different types of habitat is with a Biodiversity Significance Score (BSS) where BSS_i represents the biodiversity value of i's remnant vegetation. The BSS draws on information about the scarcity of vegetation types and its Ecological Vegetation Classification[1] (NRE 1997).

[1] Ecological Vegetation Classes indicate whether vegetation is presumed extinct, endangered, vulnerable, depleted and so on.

2. The improvement in habitat associated with landholder actions – There are a number of actions that landholders can take to improve the condition of habitat on private land. These include fencing to exclude stock from remnant vegetation, controlling environmental weeds and pests, minimising habitat disturbance by not harvesting firewood etc. The value of these habitat management actions can be expressed as a Habitat Services Score (HSS) where HSS_i represents the change in quality of habitat from *i*'s habitat management actions (Parkes *et al.* 2003).
3. A bid – The nominal bid (b_i) submitted by *i* to protect and enhance the remnant vegetation offered into an auction.

This information is summarised in a Biodiversity Benefits Index (BBI) for each landholder *i*:

$$BBI_i = \frac{BSS_i \cdot HSS_i}{b_i}. \tag{1}$$

Assume for simplicity each *i* has only one site of remnant vegetation to offer in the auction. This means, in the following discussion that *i* can be referred to as site *i* or landholder *i* interchangeably.

The government purchases *i* on the basis of equation (1). The higher the BBI_i, the more desirable it is from a biodiversity perspective and a budgetary cost-minimisation perspective. BBI_i is positive in BSS_i and HSS_i but negative in b_i. So, by using BBI to explicitly measure the desirability of *i*, the government rewards high BSS_i and HSS_i but punishes high b_i. Landholder *i* knows HSS_i and determines b_i endogenously. Following Cason *et al.* (2003), BSS_i is not revealed to *i*. This means *i* faces uncertainty of BBI_i. Given this, we can rewrite (1) as:

$$E[BBI_i] = \frac{E[BSS_i] \cdot HSS_i}{b_i} \tag{2}$$

where $E[\cdot]$ denotes expectations of the variables in square brackets.

The government also has a fixed budget allocated to the auction of some amount *M*; and purchases the most valuable *i* on the basis of equation (1) until the budget constraint binds. From landholder *i*'s perspective there are two sources of uncertainty: (i) uncertainty of BBI_i as given by equation (2); and (ii) whether or not the addition of *i* to the government's purchases violate the budget constraint. We can summarise the probability of b_i being accepted by government as:

$$\Pr(b_i\ accepted) = 1 - F(b_i) \tag{3}$$

where, $F(b_i)$ is the cumulative probability distribution function of b_i. In writing equation (3), we make the simplifying assumption that landholder i bases expectations about succeeding in the auction on the choice of b_i and not on HSS_i or $E[BSS_i]$. This may be plausible if landholders do not have any way of determining the relative value of HSS_i or $E[BSS_i]$. Given equation (3), i will submit b_i if the expected utility from participation exceeds reservation utility:

$$U_i(\pi_i^1 + b_i) \cdot (1 - F(b_i)) + U_i(\pi_i^0) \cdot F(b_i) > U_i(\pi_i^0). \tag{4}$$

Following Latacz-Lohmann and van der Hamsvoort (1997), U_i is a von Neumann-Morgenstern utility function for i that is monotonically increasing and twice differentiable. π_i^0 and π_i^1 is reservation profit (e.g., agriculture on site i) and profit from conservation of site i, respectively. Assume $\pi_i^0 > \pi_i^1$ and so by the monotonicity of $U_i(\cdot)$, $U_i(\pi_i^0) > U_i(\pi_i^1)$. In equation (4), the first term on the left-hand side is the expected utility from succeeding in the auction, and the second term on the left-hand side is expected utility from not succeeding. Equation (4) can be seen as the participation condition; for i to participate in the auction, expected utility of participation must be strictly greater than non-participation. If we assume all i are risk-neutral we can rewrite equation (4) as:

$$\begin{aligned} &(\pi_i^1 + b_i) \cdot (1 - F(b_i)) + \pi_i^0 \cdot F(b_i) > \pi_i^0 \\ &(1 - F(b_i)) \cdot (\pi_i^1 + b_i - \pi_i^0) > 0. \end{aligned} \tag{5}$$

Equation (5) follows from the definition of risk-neutral agents: such agents do not care about the variablity of utility, only the net utility gain. If we assume i is risk-averse, the main findings do not significantly alter (Latacz-Lohmann and van der Hamsvoort 1997). Equation (5) can be viewed as the optimisation problem for i where the choice variable is b_i. Taking derivatives of equation (5) with regard to b_i yields:

$$\begin{aligned} &(1 - F(b_i)) - f(b_i) \cdot (\pi_i^1 + b_i - \pi_i^0) = 0 \\ &\pi_i^1 + b_i - \pi_i^0 = \frac{(1 - F(b_i))}{f(b_i)} \\ \therefore \quad &b_i^* = \pi_i^0 - \pi_i^1 + \frac{(1 - F(b_i^*))}{f(b_i^*)} \end{aligned} \tag{6}$$

where $f(b_i)$ is the probability density function associated with $(1 - F(b_i))$. An economic interpretation of $f(b_i)$ is that it represents the marginal change in probability of i's bid being accepted with a change in b_i. b_i^* is the optimal bid submitted by a risk-neutral landholder. b_i^* is increasing in opportunity cost of protecting and enhancing site i (i.e., $\pi_i^0 - \pi_i^1$) and information rents (i.e., $(1 - F(b_i^*))/f(b_i^*)$. Note that (6) is not the solution to the landholder's bidding problem but merely provides us with a convenient way of analysing the composition of bids (for the solution to this problem see Latacz-Lohmann and Van der Hamsvoort 1997). Landholders will submit higher bids the more costly conservation is on their property. The intuition behind information rents may not be so obvious. Information rents arise where there is asymmetric information; in this case, i holds information that is valuable to the government – the opportunity cost for i of remnant vegetation conservation. The government in effect 'bribes' i to reveal this information through the payment of information rents. From (6), information rents are represented by the quotient of probability of b_i being accepted and the marginal change in probability with regard to b_i; in other words, information rents depend on the trade off between the probability of acceptance and the marginal change in probability. Also from (6), information rents deviate from the first-best, perfect information outcome by $(1 - F(b_i^*))/f(b_i^*)$. Formally, the first-best outcome is:

$$b_i^{FB} = \pi_i^0 - \pi_i^1. \tag{7}$$

The first-best bid is purely dependent on the opportunity cost of conservation (for a more general explanation see Laffont and Martimort 2002). A comparison of (6) and (7) suggests that asymmetric information imposes costs on the government and hence, the use of a first-price sealed bid auction may be a second-best solution. To see this, note that information rents are increasing with the rising probability of b_i being accepted by the government. Landholder i will increase information rents if the probability of acceptance is higher. Information rents are decreasing in $f(b_i)$, the marginal change in $(1 - F(b_i))$ as a result of a change in b_i. So, the more sensitive the probability of acceptance is to b_i, the lower are information rents. The general idea that bids are greater than opportunity cost (because of information rents) is supported by experimental economic studies such as Cason *et al.* (2003).

4. Results

Table 1 provides summary statistics of participation in the auction of nature conservation contracts. A total of 126 expressions of interest were received from landholders within the regions in which the pilot was conducted. These landholders were visited by a field ecologist who assessed the quality and significance of the native vegetation (BSS) on the site and discussed management options (HSS) that might be considered by the landholder. Following field visits, 98 bids were received in which landholders

Table 1 Participation in the trial

	Expression of interest	Bids	Contracts
Participation (no.)	126	98	73
Sites assessed (no.)	223	186	131
Area of sites (ha)	3845	3478	3160

Table 2 Actions undertaken by landholders

Landholder commitments	Number of sites	% of sites
Retain large trees	182	81.6
Retain other standing trees	174	78.0
Exclude stock	195	87.4
Retain fallen timber	194	87.0
Control rabbits	202	90.6
Control weeds	136	61.0
Supplementary planting or revegetation	82	36.8

nominated conservation actions and an offer price submitted as a sealed bid. All bids were ranked according to a Biodiversity Benefits Index (see equation (1)) and contracts were allocated up to a budget constraint. A total of 73 of these bids were allocated contracts.

Contracts allocated in the auction were written against a sequence of inputs and actions specified in management agreements over a three-year period. An initial payment was made to successful bidders to cover capital costs where specified (e.g., for constructing fences), with annual progress payments made on the basis of performance. A budget of $A400 000 enabled contracts to be established for 3160 hectares of habitat on private land. Table 2 indicates the management actions included in the successful contracts. From this table it can be seen that most of the budget was allocated to improving remnant vegetation rather than to recreation of habitat through supplementary planting. Revegetation actions were selected on only 37 per cent of sites offered to the auction.

A survey of both participants in the auction and non-participants in the pilot region (sample of 380) was conducted to provide information about the characteristics of bidders. The major conclusion to be drawn from these data is that participants in the nature conservation auction were a random draw of the rural population in the pilot areas with respect to age, education attained, agricultural enterprise mix etc. (Ha *et al*. 2002). Participants were more likely than the population to be environmentally aware (signified by membership of an environmental organisation) and to operate relatively less intensive agricultural enterprises.

Table 3 General bio-physical characteristics of landholders

Variable	Mean	Coefficient of variation
Area (ha.)	27.07	1.51
BSS (units)	36.17	0.31
HSS (units)	250.83	1.61
Bid ($A)	4607.29	0.67
HSS/Bid	0.052	1.46

BSS, biodiversity significance score; HSS, habitat services score.

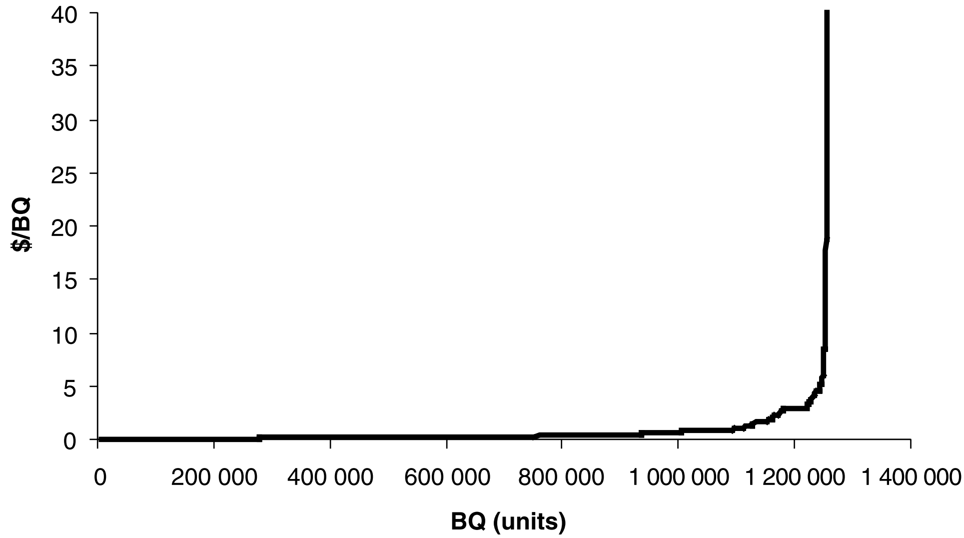

Figure 2 Marginal cost curve. Biodiversity quality (BQ).

The mean and coefficient of variation for selected bio-physical characteristics are shown in table 3. Area of site, HSS and HSS/Bid are highly variable. In contrast, BSS and Bid have relatively lower variability. Five vegetation classes were represented in the bids, these are: lower slopes hills or woodlands; box-ironbark forests and woodlands; riverine grassy woodlands or forests; plains grassy woodlands or forests; and dry forests.

4.1 Analysis of bids

Drawing on information from the bids, figure 2 illustrates the cost of generating additional units of biodiversity. The horizontal axis depicts the total quantity of biodiversity supplied, weighted by biodiversity quality (BQ) where bids are assembled in ascending price order. These units are the numerator of the BBI as given in equation (1): the biodiversity significance score times the HSS. The bids shown in figure 2 are inclusive of any 'information rents' that bidders may have included in their bid price[2] as in equation (6): we assume here that opportunity costs and information rents make up bids. However, we will henceforth refer to this curve as a marginal cost or supply curve for biodiversity from the auction inclusive of the social cost of information rents. This is different to the characterisation of Latacz-Lohmann and Van der Hamsvoort (1998), who differentiate the supply curve on account of it being exclusive of rents.

As shown in figure 2, the supply curve for biodiversity is relatively flat over much of the quantity range, but then transforms to relatively steep as the quantity of BQ exceeds 1.2 million units. Further analysis of marginal and unsuccessful bids revealed that these bids were uncompetitive because of the low conservation status and or habitat services nominated rather than the bid price offered.

Although the pilot auction was conducted without a reserve price, future nature conservation auctions would benefit from a reserve price strategy, particularly if run sequentially. The marginal cost curve for biodiversity provides information that would be useful in formulating a reserve prices strategy. With experience the government agency could withhold some funds from one auction in anticipation of more cost-effective bids in the next round.

One of the theoretical attractions of an auction of conservation contracts noted by Latacz-Lohmann and Van der Hamsvoort (1997) was that competitive bidding would reveal information about the opportunity cost of individual landholders thereby leading to improved cost effectiveness of nature conservation programs (see equation (6)). Information about individuals' opportunity costs is particularly important when agents are heterogeneous and hold private information of relevance to policy makers. Figure 3 plots the actual bids received in the auction expressed in terms of the improvement in habitat per dollar of bid (HSS/\$A on the horizontal axis) and the biodiversity significance of each bid as measured by the BSS. Both axis are scaled from 0 to 100. Bids at the top-right of the diagram represent high biodiversity significance and low offer price – the preferred bids. This figure illustrates that there was in fact a large variation in both the price of improvements to habitat quality and the significance of biodiversity represented on each site. While the average bid was around \$A4600 with relatively low variation between bids (coefficient of variation 0.67) the variation between bids is magnified when bids are compared on the basis of the

[2] Thus the farmers may have information about the Government's willingness to pay for biodiversity on their land, and adjust their bids accordingly.

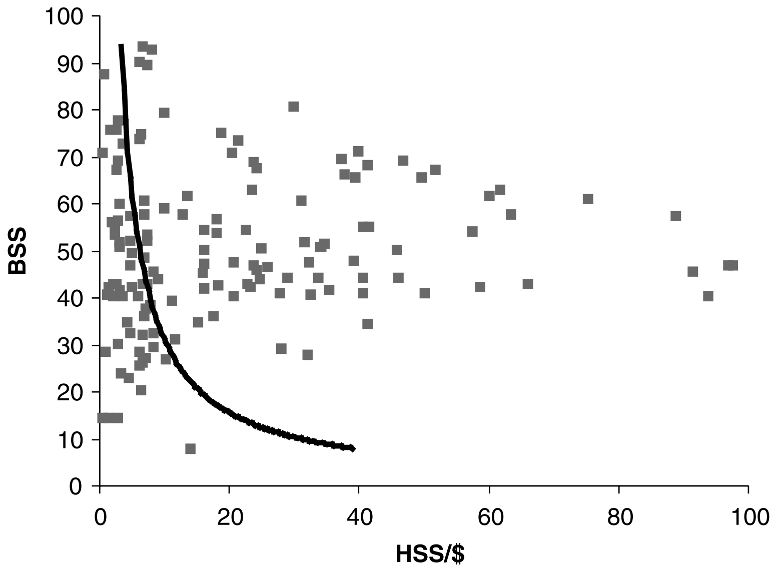

Figure 3 Threshold-Biodiversity benefits index (BBI) and bid data. Habitat services score (HSS).

habitat service provided per dollar of bid. From table 3, HSS/$A has a coefficient of variation of around 1.46. Revelation of otherwise hidden information about costs and the conservation service offered allowed program administrators to take advantage of this diversity and increase the quantum of biodiversity improvement for the given budget.

A budget line has been identified in figure 3. This budget line was constructed equalising all bids' BBI with the last successful bid. This was done by changing all the bids until all BBI were equal to the last successful BBI. All bids to the right of the budget line were successful while those to the left were unsuccessful. The horizontal distance between the threshold BBI and any successful bid represents a surplus or rent to the government agency running the auction. Holding all else constant, this is the gain to the government agency from this contract. Note, again, that value is maximised by allocating the contracts to the lowest bidders. Choosing to do so at the bid, or offered price (i.e., adopting a discriminatory price auction) implies that value was apportioned favourably for the state.

Although it is difficult to compare the results from the auction with other mechanisms, it has been possible to examine how a hypothetical fixed-price scheme would perform compared with the discriminative price auction used in the pilot. To make this comparison, we must assume that bidder behaviour would not change if a fixed-price scheme were used. Specifically, we assume that the ordering of bidders would not change with

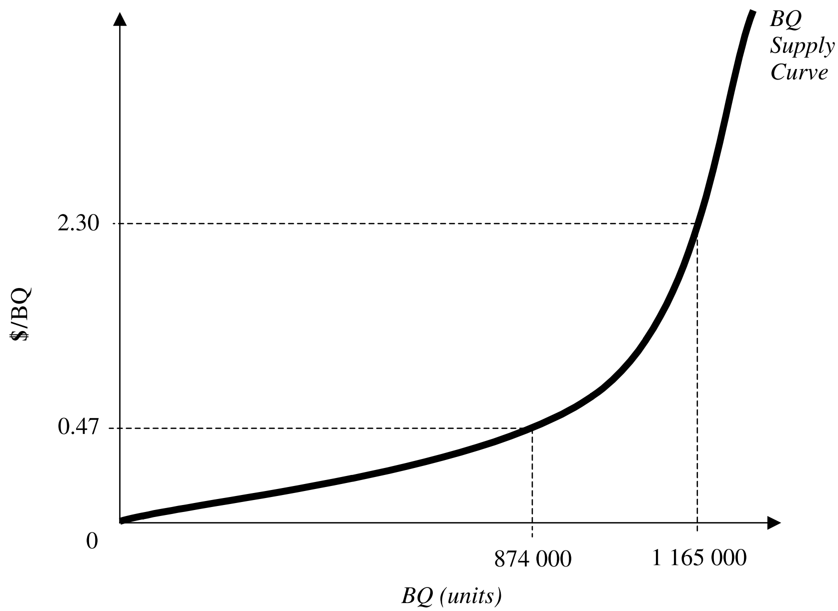

Figure 4 Comparison on fixed-price versus discriminative price auction. Biodiversity quality (BQ).

different schemes which means the marginal bidder does not change and, as a result, the value created does not change between the schemes. We justify this assumption by first recognising that it is likely that individual landholders' behaviour is likely to change with different schemes but a priori theory or empirical evidence does not allow us to assume how the supply curve changes.

Figure 4 illustrates that in a fixed-price scheme, an agency would pay each successful landholder the same price: the price of the marginal offer. 'Price' here is dollars per BQ. For the last unit of biodiversity purchased in the auction, this marginal price is approximately $A2.30 (see figure 4). This is the price that an agency would need to offer to all landholders to generate the same supply of biodiversity made available from the price discriminating auction (approximately 1.16 million units of biodiversity). A fixed-price scheme would require a budget of approximately $A2.7 million (almost seven times more than the actual budget) to elicit the same quantity of BQ units as the discriminative price auction. Looked at another way, figure 4 shows that – for the same budget of around $A400 000 – a fixed-price scheme would give an agency approximately 25 per cent less biodiversity. The supply of biodiversity falls from 1.165 million to 0.87 million units of biodiversity with a fixed-price scheme compared with the discriminative price approach.

5. Discussion and summary

The pilot auction has shown that it is possible to create at least the supply side of a market for nature conservation and in conjunction with a defined budget, prices can be discovered and resources allocated. Characterising nature conservation on private land as a problem of asymmetric information has improved our understanding of why this and related environmental markets are missing or ineffective and has introduced an alternative policy mechanism to those currently available. In theory, auctioning nature conservation contracts offers many advantages over planning, command and control, voluntary approaches and fixed price policy mechanisms. This is not to suggest that auctions are always a viable replacement for these other mechanisms. It does, however, add a new mechanism to the environmental policy tool kit.

Many important design issues have been addressed in the process of implementing the auction. Besides choices about auction format, contract design and the specification of biodiversity preferences, many practical choices arise concerning communication with landholders, skills required to successfully run an auction, and timing of activities. These factors all influence the performance of the auction.

Our preliminary analysis shows that where there are heterogeneous agents and non-standard environmental benefits, an auction potentially offers cost-savings over fixed-price schemes, such as subsidies and tax concessions. This comparison is made on cost-effectiveness, rather than economic efficiency grounds. For the budget available and the bids received, it has been shown that a price discriminating auction would reduce by seven times, the cost of achieving the same biodiversity improvement using a fixed-price approach. Moreover, a fixed-price approach essentially reveals the wrong information from the parties involved. A grants based approach (e.g., a subsidy) requires the landholder to reveal the actions that they believe will improve the environment (when this information is perhaps held by environmental agencies); and agencies reveal the price that will be paid for these actions (when this information is often held by landholders).

The attraction of an auction of nature conservation contracts rests in the value of information revelation. The pilot auction was designed to reveal specific but previously hidden information from the agency responsible for nature conservation and from landholders. As part of the auction, the government agency revealed information about the improvement in biodiversity associated with changes in land management (the HSS) and the relative conservation status of different areas of vegetation (the BSS). This information would significantly improve priority setting for nature conservation, whatever the mechanism employed. Landholders, likewise revealed information about their opportunity costs (albeit imperfectly) allowing government to take advantage of heterogeneity in landholders' opportunity costs. Hypothetically, if a landholder was conservation minded, the pilot provided an opportunity for the landholder to share the cost of conservation.

6. Future directions

The pilot auction of conservation contracts, by its very nature, was necessarily simplistic. It was constructed essentially as a one-shot game between the government and private landholders. Before this approach could be applied more generally auctions would need to be designed within a repeated game context and indeed across multiple outputs (e.g., biodiversity, salinity, water quality etc.).

Design of a sequential auction, however, would be more complicated than the pilot because landholders could be expected to learn through rounds of the auction. Under these circumstances, landholders could change their bidding strategies and raise the cost of nature conservation to the agency. For example, Riechelderfer and Boggess (1988) found that bidders in the Conservation Reserve Program – which is a sequential auction – revised bids from previous rounds by offering bids at the reserve price. The reserve price in this case was set on a per hectare rate and when landholders learnt this reserve price, they anchored their bids accordingly.

Another interesting development would be to design auctions capable of dealing with multiple environmental outcomes from landscape change where these outcomes are complementary and or competing. Revegetation of parts of the landscape may, for example, improve habitat and address land degradation. Auction theory is starting to make inroads into questions of how complementarities make market design difficult. Milgrom (2000) shows that complements to some bidders but not to others pose a threat to the existence of equilibria. Roth (2002) also notes that this problem arises in labour markets, such as the medical internship placement system, where couples prefer coplacement.

One of the most interesting design issues with the pilot auction of conservation contracts was the extent to which information was made known to landholders prior to formulation of their bids. For the pilot auction, information about the BSS was withheld from landholders but the HSS was fully revealed to bidders. As noted earlier, this strategy was empirically supported by the findings of Cason *et al.* (2003). Although the strategy to withhold information was adopted for cost-effectiveness reasons, other considerations suggest that full disclosure of information about biodiversity significance may be appropriate. In the short-run, withholding some information limits the scope for landholders to extract information rents from the auction. Clearly, landholders who know that they have the only remaining colony of some plant or animal, will be able to raise their bids well above opportunity cost, compared with a situation where this information was not known by the landholder. The alternative strategy also has merit in that: (i) the information rents that accrue to landholders would influence land markets and encourage investment in nature conservation; and (ii) landholders would know exactly what scarce biodiversity assets they have and could self-select into the auction process; that is, there may be a better matching between government priorities and the bidders in an auction.

Finally, other indirect benefits could arise from the application of auctions and other market approaches to environmental management. For example, information about the marginal cost of habitat conservation would assist public sector decision-makers in allocating resources between conservation investments on public (e.g., national parks) and private land. Similarly the emergence of more formalised and quantitative methods of expressing relative preferences for alternative environmental actions may facilitate development of more robust offset and trading schemes.

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