Creating markets for environmental goods and services from private land

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Abstract

The way land is employed and managed has a significant impact on the environment. Based on analysis of one region of Australia it has been estimated that changes in the landscape over the last 200 years have significantly increased the volume of stream flow; reduced the quality of water in rivers and streams; marginally increased the area of dryland salinity; and caused a large decrease in the stock of terrestrial habitat. While private landholders are rewarded for investment in commercial activities, such as commodity production, the current economic environment lacks incentives to reward investment in the environment. This paper reports on the results from a field pilot where landholders were exposed to a more "complete" set of markets including a tradeable emission permit for carbon (a private good) and an auction of conservation contracts for public goods including habitat, water quality and dryland salinity control. The pilot illustrates that the new institutions created provide an economic environment in which landholders determine the optimal mix of commodity production and environmental goods and services. An efficiency gain of at least 30% was achieved when information asymmetry (adverse selection) was resolved. Moral hazard problems were only partially addressed in the pilot. There are residual contract design issues to be resolved, including those relating to attribution of outcomes, multiple outcomes, long time scales and learning contracts. Finally, the pilot illustrates that there are potentially large savings to government from creating markets for different environmental goods and services because of the multiple outcomes that are derived from land use change. Carbon emitters were shown to partially fund the production of public goods such as habitat, water quality and salinity control.

1. Introduction

In most countries, the landscape has been extensively modified due to clearing of native vegetation, the introduction of exotic plant and animal species and increased physical disturbance of soils associated with crop and pasture activities. The way land is deployed influences both income and the stock of environmental assets. The environmental goods and services (EG&S) derived from these stocks provide collective benefits to those who have no pecuniary interest in land, but in some cases can also be beneficial to land owners themselves. It is widely recognised that institutions/markets for these EG&S are missing or inefficient, leading to sub-optimal investment in conservation and overinvestment in private goods such as commodities. Over long periods of time, the accumulated effect of this misallocation of resources becomes evident as species extinction and degradation of air and water resources.

Environmental goods and services can generally be classified as either point-source or non-point-source. There are now numerous examples of successful management of point-source emission problems through tradeable emission permit schemes including the NOX scheme in the US and the Hunter River Salinity Program in Australia. Under certain circumstances pollution taxes and offset schemes have also been employed (see Stavins (2001); Schmalensee (1996); and Faeth (2000)). While many of these programs have proven to be both efficient and practical, much less progress has been made on non-point-source problems despite the observation that land use change and fossil fuel use have been identified as the two most important human induced influences on the environment (The United Nations Intergovernmental Panel on Climate Change).

The problem with non-point-sources is that it is not possible to attribute ambient pollution to the actions of individuals since property rights are difficult to define and transactions involving these rights become problematic. One solution could be for government to purchase and manage land, as occurs with national parks and crown land, for the purpose of producing EG&S. This approach generally involves high transaction costs if sites are spatially dispersed and/or where managers (in this case government) have little or no local knowledge. National parks usually involve large tracts of land because this reduces transaction costs. A second option would be for the purchaser of EG&S (the principal) to delegate responsibility for environmental management to existing landholders (the agent) through contractual agreements. This approach has a number of advantages, not the least of which is the potential to utilise local knowledge about the costs and technologies relevant to alternative land uses. The disadvantage, as noted by Laffont (2002), is that the act of delegation confers an information advantage to the agents (landholders) because they have access to information that is not available, but valuable, to the principal. There are two types of information problem to be resolved in this case. These are referred to as hidden information (leading to adverse selection) and hidden actions (leading to moral hazard). Resolving these problems imposes costs on the principal but if not addressed reduces economic efficiency in the environment sector.

Examples of environmental programs that have employed contractual arrangements with landholders to procure non-point-source EG&S include: the Conservation Reserve Program (CRP) in the US; the Nature 2000 program as it is applied in several member countries of the European Union (Denmark, the UK and France); some African countries, such as Kenya; Australia (Stoneham 2003) and Germany (Hilden 2004). There appear to be three problems with these programs. Without access to complex biophysical information systems, it is not possible to adequately address the hidden information problem relevant to the environment; many programs do not take account of multiple outcomes that arise from each land use/practice change; and the contracts employed in these programs have generally not been incentive compatible.

This paper frames non-point-source environmental management on private land as a principal-agent problem. New institutions were then designed to provide incentives for the efficient production of EG&S. A field pilot was completed to reveal the responses of landholders to these new institutions/markets. Following the observation that one investment in land use change/management generates multiple environmental outcomes, landholders in the pilot were exposed to a competitive market (auction of conservation contracts) for non-point-source EG&S (public goods) and a tradeable emission permit market for carbon. Government was the purchaser of EG&S with public good attributes through a fixed environmental budget and an exogenously determined price of carbon was employed to represent demand from emitters of carbon. In both cases, landholders were competing for contracts to supply bundles of EG&S. This institutional setting provided incentives for landholders to include the environment in investment and management decisions for land. In effect, land use was determined with reference to commodity markets as well as previously missing markets for EG&S. A significant investment was made prior to the pilot to develop biophysical representations of the various EG&S relevant to the pilot region (see Beverly (2003) and Eigenraam (2005)).

2. Private land use and the environment

The landscape in much of Australia has been significantly altered in the 200 years of European settlement. Across Victoria, significant tracts of land have been cleared of native trees and grasses for the purpose of agricultural production (see Figure 1). The impact of landscape change has been estimated in one sub-catchment (the Avon-Richardson) using biophysical models (Eigenraam 2005) and ecological metrics (Parkes et al 2003) (see Table 1).

This analysis suggests that in the pre-European landscape, stream flow, measured in Giga Litres (GL), was estimated to be approximately four times lower than today. The area of land adversely affected by dryland salinity (measured as the area of land where water tables were less than 0.8m depth) was estimated to have increased from 17,375ha to 45,374 ha in the 200 years of European settlement. This represents only a small decrease in the stock of productive land from 95% of the land mass to 87%. Table 1 reports that there has been a dramatic reduction in the stock of terrestrial habitat due to extensive clearing of vegetation and the introduction of threatening processes such as weeds, pests and grazing by stock. Using the metric developed by Parkes et al (2003), it has been estimated that terrestrial habitat has declined to around 4% of the initial stock.

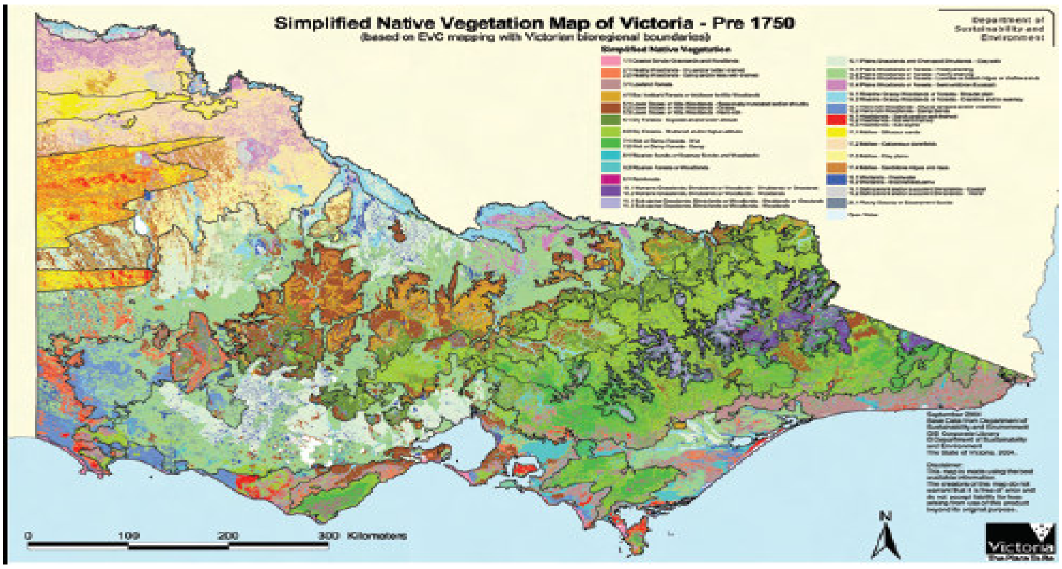
Biophysical modelling also reveals several important characteristics of the environment and its interaction with land use change. These include:

Intervention type – There are many different types of intervention that could be made in the landscape. Each action or investment precipitates a different set of environmental outcomes. Trees, for example, have significantly different impacts on the hydrology (both surface and sub-surface systems) compared with annual crops or pastures. In general, it can be shown that revegetation generates more carbon sequestration, intercepts more water but produces lower terrestrial habitat services than restoration activities. Similarly changes to plant species, particularly the substitution of annuals for perennials, can cause large changes in hydrology over extended periods of time.

Location of intervention - The location of interventions in the landscape significantly affects the EG&S generated. Results from the biophysical models indicate that a plantation of trees in one location is estimated to significantly reduce stream flow while in other locations a minimal impact is predicted.

Joint supply – Each intervention generates a unique bundle of environmental services which are jointly supplied. Based on a random sample of landscape interventions across the entire catchment, it has been estimated that 73% of sites generated more than two environmental goods and services. At the whole of catchment scale, Table 2 indicates that there are generally low correlations between the different EG&S generated. From this table it can be seen that there are

Figure 1: Landscape change following European settlement



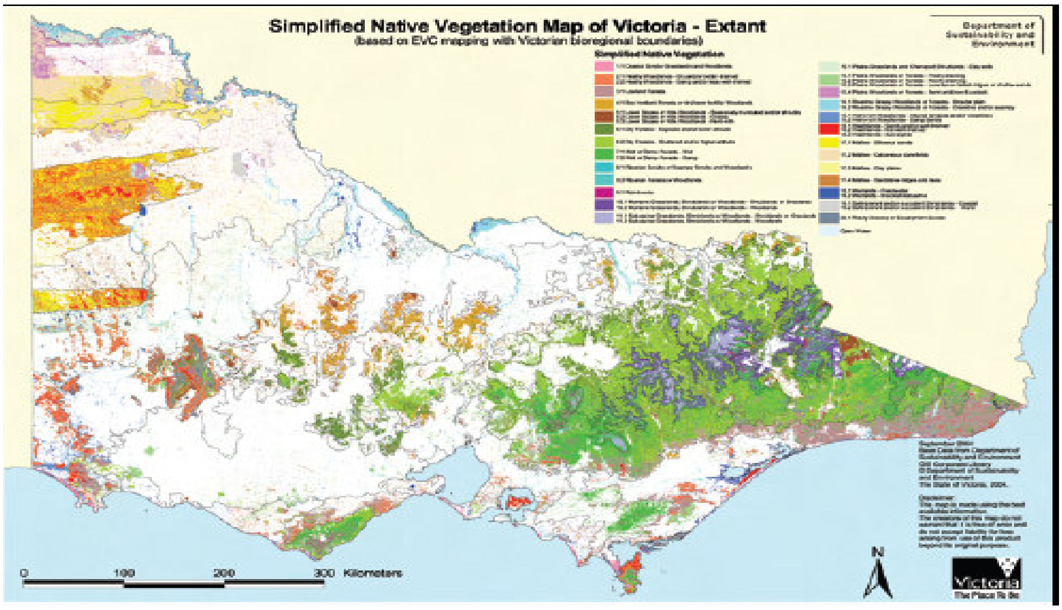


Table 1: Comparison of changes in environmental stocks from land use change

	Pre-European landscape	Current landscape	Change %
Annual stream flow (GL)	19.8GL	81 GL	409%
Area of land with groundwater > 0.8m)	352,625 ha	324,626 ha	8%
Habitat (habitat hectares)	370,000	14,000	96%

both positive and negative correlations evident between different environmental domains.

Timing of responses – The time lag between intervention in the landscape and impact on the environment varies according to the underlying biophysical processes. Some groundwater systems (such as those on the plains) move to a new equilibrium very slowly (eg. 200 years) following intervention, while in others hydrological equilibrium is restabilised relatively quickly (eg. 50 years). Similarly, the time taken to achieve improvements in habitat quality varies with the type of intervention. Restoration of existing remnants tends to generate habitat improvement more rapidly than revegetation of cleared land.

Natural variability - The environment is subject to a range of stochastic, exogenously determined influences such as weather, pest and weed incursions. For example, the quantity of carbon sequestered, the volume of stream flow and habitat stock depend on the amount and distribution of rainfall. Sergerson (1988) describes non-point-source pollution as an ambient level which can be represented as a probability function that is conditional on the abatement practice. The nature of the probability function is determined by the interaction between exogenous variables, such as rainfall, radiation, temperature; the biophysical processes relevant to each domain of the environment; and land use/management practice.

Other characteristics of the environment may be relevant, including the existence of thresholds/discontinuities in the provision of environmental services and the existence of interdependencies between different actions/costs taken in different locations of the landscape.

Table 2: Correlation matrix : whole of catchment

	Aquatic function	Carbon	Saline land	BLP	LC
Aquatic function	1				
Carbon	0.17	1			
Saline land	0.16	0.06	1		
BLP	0.03	-0.07	-0.09	1	
LC	0.09	-0.06	-0.17	0.64	1

3. An economic framework

Landholders are economic agents: they have specific goals, objectives, risk preferences, have command over a unique set of resources and hold information about costs, profit margins and production possibilities. In some cases, they employ their resources of land, labour and capital to generate commodities. In other cases, landholders might employ land to generate recreation services. In either case, markets are the institution employed in western economies to facilitate transactions between buyers and sellers of goods and services. It is through this institution that landholders use their information (about supply technology and costs) combined with information from other agents (eg. buyers of commodities or sellers of inputs) to allocate resources between alternative uses. Markets are the institution employed to resolve the questions of which mix of commodities to produce and how much to supply.

It is clear from the previous section that landholders could also combine resources in ways that supply environmental goods and services. However, markets for many of these EG&S have not evolved and land use decisions tend to be made without consideration of the returns that might be available from the production of EG&S. This missing markets/institutions problem distorts land use decisions toward commodities and against the production of EG&S.

The economic problem then is to design new institutions that contain incentives to reward private landholders for producing EG&S such that each landholder efficiently allocates resources to the optimal mix of public and private goods. This problem is further complicated because the production function that describes the way inputs are transformed into environmental outcomes is extremely complex. As noted earlier, cause and effect are separated by space and time through buffered systems, the EG&S produced depend on the type of intervention, the location of intervention, are jointly supplied and subject to stochastic influences.

The first step in designing the institution needed to correct the "missing environmental market" problem is to diagnose the precise reason/s why markets for these goods and services have not evolved naturally. Once these are well understood it may be possible to design and create purpose-built institutions that facilitate transactions between those that want to procure environmental outcomes and those able to supply these goods and services. In doing so there are both demand and supply side problems to be considered.

3.1 The demand-side problem

It is widely understood that markets for EG&S fail because some of the information needed to facilitate transactions is not available – i.e. information about the "willingness to pay" for additional units of environmental goods and services. For private goods and services, markets provide a means for buyers of goods and services to reveal this information. When consumers make consumption choices, these decisions are contingent on knowledge about the improvement in well-being that is to be derived from an additional unit of consumption. This information revelation process does not, however, exist with public goods. Without this information it is difficult to determine how much effort should be invested in improving the environment. It has also proven difficult to find a surrogate method of revealing information about willingness to pay for public goods because in the words of Laffont and Martimort (2002) "the mechanism used for collective decisions must solve the incentive problem of acquiring private information that agents have about their preferences for public goods".

3.2 The supply-side problem

Information about willingness to pay for additional units of environmental services represents only one part of the information puzzle. To allocate resources efficiently, information about the cost of procuring additional units of environment will also be required. In the case of private land, this information is known only by landholders (it is private information) and costs, technologies, and land quality vary from site to site. Information about supply prices is not known by government or other agents interested in procuring EG&S and landholders have an incentive not to reveal this information. Asymmetric information is now recognised as one of the causes of market failure in many domains of the economy (Akerlof 1970) and specific types of intervention will be required to reveal relevant information before efficient use of resources will occur. Asymmetric information can cause problems prior to a transaction because some information is hidden from one relevant party. This is referred to as the *hidden information* problem and if not addressed causes *adverse selection* where the wrong suppliers (those with high supply costs) are selected into supply contracts. The second information problem occurs after contracts have been awarded because it is often difficult to observe the actions of those who have been delegated the task of providing goods or services. This is called *hidden actions* (also referred to as *moral hazard*). As Laffont and Martimort (2002) note supply-side problems arise because delegating responsibility for supply to a third party creates an information advantage to the agents since they have access to information that is not available, but valuable, to the principal. Resolving adverse selection and moral hazard problems impose costs on the principal but if not addressed will reduce economic efficiency in the procurement of EG&S. A number of papers including Wu (1996); Xepapadeas (1991); Fraser (2002); Latacz-Lohmann and Van der Hamsvoort (1997); Moxey (1999); and Choe (1998) have framed the non-point-source problem in this way as a principal-agent problem. A formal representation of moral hazard and adverse selection is presented in Appendix 1.

3.2.1 Adverse selection

There are three policy mechanisms that can be considered to deal with adverse selection:

Menu of contracts - Whilst a menu of contracts approach has been employed for adverse selection in insurance markets, there have been no known applications of this approach in the environmental procurement field. Ferraro (2005) notes that designing a menu of contracts that is incentive compatible and satisfies participation constraints whilst maximising the environmental authority's objective function requires "knowledge about the distribution of landowner types and sophisticated calculations by conservation practitioners".

Costly to fake signals - A second approach to manage adverse selection is to gather information on observable landowner attributes that are correlated with opportunity costs and to use these attributes to establish contract prices. Ferraro (2005) notes that his approach is common in US agri-environmental schemes where posted contract prices differ to reflect soil type, distance to roads and markets, habitat type and other variables.

Auction - Auctions are a set of rules and processes that harness competition for the purpose of revealing an agent's type, i.e. whether they are low-cost or high-cost suppliers. Auctions are used to allocate conservation contracts in the Conservation Reserve program (US), for biodiversity conservation in Australia (Stoneham 2003), and in Germany.

Each approach aims to reveal landholder type and each comes at a cost because the conservation agency must invest in information revelation processes and a system of rewards to landholders to reveal private information. Importantly, the principal will be required to pay landholders a rate above their true opportunity cost to encourage revelation of this information. This is referred to as an information rent that accrues to landholders because private information about their "true' opportunity cost has conveyed some degree of market power. The choice of which of the three mechanisms to employ reduces to a comparison of transaction costs involved in information revelation.

The fundamental difference between an auction, a menu of contracts approach and the costly to fake signal approaches is that information asymmetry between the conservation agency and the landholder is addressed through competition in the case of an auction, through self-election in the case of the menu of contracts, and through correlation with observable attributes in the signalling approach. In the application to private land there are several information advantages of an auction over alternative methods of dealing with adverse selection. Unlike the menu of screening contracts, auctions do not require the conservation agency to specify the distribution of landholders' types (Ferraro 2005). Landholders reveal this distribution through their bids. Whereas auctions use competitive bidding to reduce the attractiveness of low-cost landholders claiming to be high cost, screening contracts accomplish this goal by specifying a low level of environmental services from contracts aimed at high-cost landowners. For this approach contracts will need to be designed to ensure that the inefficient type gets no rent, but the efficient type gets the information rent above opportunity cost. This is a difficult design problem that would rely on detailed *a-priori* information about participants.

Latacz-Lohmann (2005) identifies the information management advantages of an auction compared with the alternatives. A well-designed auction facilitates revelation of specific information from the different players. Bidding is a discovery process where prices are determined through a decentralised process which takes into account the information from a range of sources. The environmental agency can design the rules (which EG&S are demanded and how they are measured) under which the competing bids are evaluated and the landholders who have private information about the cost of land use change, provide information about the cost of changing land use. Auctions can also sequence and combine information from different sources, including scientists, so that the principal obtains relevant information on which to allocate contracts. Auctioning conservation contracts to landholders does, however, require the use of complex models that convert land use change into estimates of environmental change. Provided these information problems can be managed, auctions compare favourably with a menu of contracts approach where the principal is required to make the first move by offering a menu of contracts with pre-determined characteristics. Increasing the number of contracts offered to accommodate different types will raise transaction costs because some of the information needed will be hidden from the principal. There will be similarly onerous transaction costs associated with increasing the information needed to reduce information asymmetry with the signalling approach.

The disadvantages of auctions as a means of dealing with adverse selection in the case of conservation contracts include: the need for a large pool of bidders to induce competition, the additional costs of administering an auction, and in some cases complexity. Certain types of auctions, such as those dealing with package problems, can involve complex bidding processes (eg. combinatorial auctions). It is not clear, however, that the alternatives resolve these information and aggregation problems more efficiently than an auction in this application.

There are many, often conflicting, design choices to be made in selecting the auction format for conservation programs on private land. While the Revenue Equivalence Theorem suggests that all auction formats (English, Dutch, First-price sealed-bid, Vickrey) will generate the same price on average, this is under a set of standard assumptions. If the assumptions behind this Theorem do not hold, particular auction formats may prove superior. The characteristics of the environment noted in section 2, including the existence of multi-item bundles of outcomes, joint supply, site synergies, stochastic outcomes and threshold effects, will also influence auction design. Latacz-Lohmann (2005) identifies several additional factors that need to be considered with environmental procurement auctions including: the repeated nature of conservation auctions, fixed-target vs. fixed-budget objectives, efficiency vs. cost-effectiveness objectives, different payment formats (eg. uniform–price or price discriminating), as well as a range of information management options with respect to bidders (see Cason et al (2003)).

3.2.2 Moral hazard

As noted in Appendix I there are a limited set of contracts that comply with participation and incentive constraints. In the case of pure moral hazard, where the agent carries all of the risk, the optimal contract is to pay zero if a low state occurs and a payment higher than the investment if a high-state occurs. Where the risk is shared (between the principal and agent), the optimal contract is not to cover the total cost of the agent in the low state and to give the agent a bonus in the high state.

There are a number of examples of environmental programs that have employed contractual arrangements with landholders to procure non-point-source EG&S including the Conservation Reserve Program (CRP) in the US; the Nature 2000 program as it is applied in several member countries of the European Union (Denmark, the UK and France); some African countries, such as Kenya; Australia (Stoneham 2003) and Germany (Hilden 2004). Some of these programs allocate contracts without reference to adverse selection (EU countries and Kenya), however, the CRP, Australia and Germany auction conservation contracts identify landholder type.

A number of papers have applied ideas from principal-agent theory to investigate moral hazard in the context of agri-environmental applications including Bourgeon (1995); Choe (1998) and (1999); Moxey (1999); Fraser (2001) and (2002); and Ozanne (2001). Economic theory provides some general principles about the design of contracts to manage moral hazard. Importantly, it has been shown that the optimal contract will involve the agent facing some risk. Assuming adverse selection is managed through an auction of conservation contracts, the optimal contract will be one that rewards the agent for reaching the high environmental state. This translates to a contract where landholders would be asked to invest $\overline{I}$ but would given a prepayment equal to $\bar{t}^{L} < \underline{I}$. This payment would be greater than zero where a participation constraint exists but not large enough to induce moral hazard. After termination of the contract, outcomes would be monitored and if S^{H} is realised, the landholder receives a bonus equal to $\bar{t}^{H} - \bar{t}^{L}$, otherwise he receives nothing. Ozanne (2001) and Fraser (2002) investigate the implications of contract incentive, including monitoring and penalties, where the agent is risk-averse. Risk-averse farmers facing substantial production income uncertainty will develop contract compliance strategies that promote their overall risk management goals. Fraser (2002) concludes that non-compliance can be reduced among risk-averse farmers by adjusting contracts to increase the variance of farmers' income whilst leaving the expected penalty for non-compliance unchanged.

Contract design for agri-environmental applications is, however, complicated by four factors:

Attribution – For some domains of the environment, such as water quality and groundwater accession, it is relatively easy to monitor outcomes but it is difficult to attribute this outcome to an individual landholder. In these situations, it is the collective actions of landholders that influence environmental stocks. This problem undermines the basic incentive structure noted above. Sergerson (1988); Xepapadeas (1991); Horan (1998); and Taylor (2004) have examined the contract design problem for water pollution, which is an example of an environmental outcome that can be attributed to teams of landholders rather than individuals. Sergerson (1988) notes in these circumstances that the environmental outcome is an ambient level of pollution represented by a probability density function where the objective of environmental control programs is to shift the probability density function so that the new distribution dominates the old one in the sense of first order stochastic dominance. In these situations, the free-rider problem dominates incentive design. Sergerson (1988) proposes an incentive structure where a pure tax/subsidy scheme, a pure penalty scheme, or a combined scheme can ensure optimal abatement. For multiple polluters, an approach similar to Holmstrom (1982) is described as a solution to the free rider problem. In this case, each polluter's liability depends on ambient levels that are determined by emissions from the whole group/not just the individual contribution, since at any given time individual contributions are not known or observable. This is equivalent to placing a bubble over the entire group and setting standards for the whole bubble rather than for each source within the bubble. The incentive structure within the bubble is for each polluter to pay a tax equal to the full marginal benefit of reduced ambient pollutant levels rather than just paying a share equal to the marginal benefit. The author argues that although the marginal revenue collected will exceed the marginal damages, the polluter faces the correct marginal incentives. All polluters face the same tax/subsidy rate per unit of ambient pollution regardless of whether they are likely to contribute heavily to marginal ambient levels. Even though each polluter pays the same marginal rate (per unit of ambient pollution) they do not pay the same expected rate per unit of abatement – this is contingent on site specific factors. In this incentive structure, polluters weigh the expected marginal benefits of abatement against their marginal abatement costs. Taylor (2004) proposes an alternative whereby an auction is used to elicit individual abatement costs, and teams are then formed based on groups of landholders with low abatement costs. Teams then determine a group strategy to meet given ambient pollution targets subject to stochastic weather events, with penalties for shortfalls and rewards for meeting the target.

Multiple outcomes – The participation and incentive structures embodied in contract design will also need to accommodate the observation that individual investments by landholders generate multiple environmental outcomes. While contracts could be constructed separately for each domain of the environment, this would involve duplication of mechanisms needed to manage adverse selection and moral hazard. In this situation, one landholder could be required to participate in a number of programs and multiple contracts would need to be monitored separately. There would also be difficulties in coordinating incentive structures across the various contracts that would apply to any one landholder. This is broadly the situation that applies with current policy programs where separate agencies run separate programs for different domains (habitat, water quality, salinity, pest control etc.) of the environment. One approach would be to define efficient incentive structures for each EG&S offered by each contract and to combine these according to the proportions of the different EG&S offered in each contract. Two groups of EG&S can be defined. In the first group, the environmental outcome is dependent on the actions of the individual landholder. For these EG&S an incentive contract would be offered involving an initial transfer followed by incentive payments if the high state is reached as described above. A second group of EG&S are those where groups of landholders influence the status of the environment, as is the case with water quality and groundwater accessions. In this case a team contract for a bubble of landholders relevant to the problem would apply as proposed by Sergerson (1988). This could involve a tax, subsidy or combination of both. The contract for any individual landholder would involve a mixture of these two incentive structures according to the relative proportions of each EG&S produced. A contract that provides mostly attributable EG&S and a small proportion of common outcomes would be dominated by the former incentive structure, with incentives for the team outcomes making up a relatively small component of the incentive structure.

Long time scales – For some EG&S, particularly groundwater accession, long time lags may exist before the environmental outcome is realised. In the extreme case and under an "optimal contract" landholders would not receive state contingent incentive payments for 200 years. A performance payment in 200 years would lose its incentive effects and in this case a preferred approach would be to offer a two stage contract. Stage one would include an initial low transfer with incentive payments based on outputs (eg. the growth of trees known to precipitate the outcomes desired) rather than environmental outcomes (measured reduction in groundwater depth). There are clearly important interactions between contract design and information derived from biophysical modelling. Contracts that employ outputs as a signal for performance will invariably shift risk to the principal. The optimal contract will arise from consideration of the trade-off between the costs of fading incentives in contracts with long time horizons and the efficiency costs of output (rather than outcome) based contracts. Where these compromises are needed, the principal may find the use of legally binding covenants over relevant areas of land to be a useful risk mitigation strategy.

Knowledge of landholders – A final point of interest in contract design involves the role of conservation contracts as a learning mechanism for landholders. Based on a survey of landholders who had participated in conservation contracts, Burmeister (2006) reported that site visits by a professional field ecologist, prior to bidding, and as part of the contract monitoring process, was highly valued by landholders because it provided them with information about how to produce habitat and other environmental outcomes. While landholders are generally efficient producers of agricultural commodities, they have little or no experience in producing EG&S. The contract provided landholders with a structured schedule of conservation activities. For the initial years of the contract there appears to have been a "learning by doing" process which was structured by the conservation contract. Burmeister (2006) also showed that the visual success of landholders' actions in rejuvenating habitat following landholder investment heightened interest in conservation activities and no doubt explains the high compliance rates observed. Compliance rates of over 97% were recorded and many landholders continued with conservation investments beyond the term of the contract. Where landholders are unfamiliar with the way inputs transform into EG&S (the production function) it may be feasible to design the initial phase of the contract to provide incentives for learning. Once sufficient skill in environmental production has been gained, a second phase could then involve state contingent payments as discussed earlier.

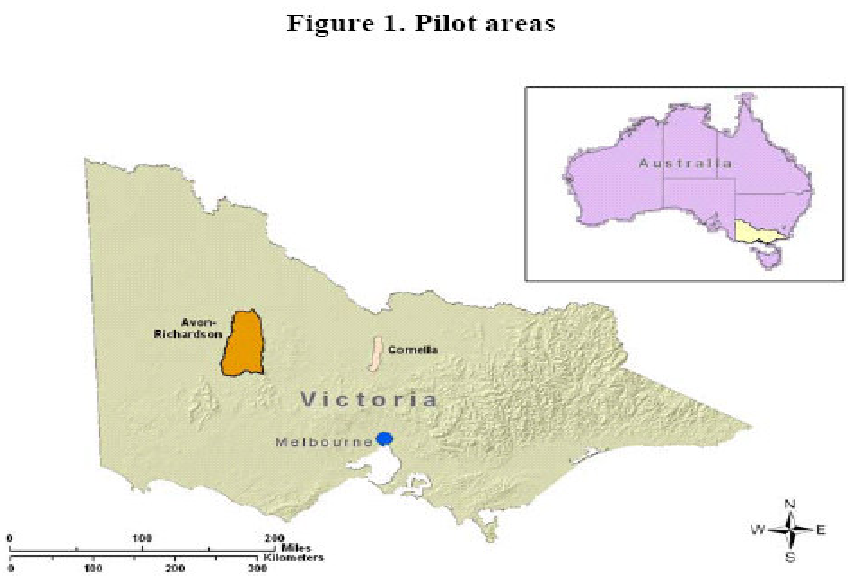
4. Results from field pilots

This section of the paper reports on the performance of a pilot designed to expose landholders to "missing markets" for environmental goods and services. The pilot was run in two sub-catchments, Avon-Richardson (370,000 ha) and Cornella (47,000 ha) in Victoria, Australia (see Figure 2). At the time of the pilot, land use in Avon Richardson (Cornella) was 52% (53%) cropping, 37% (26%) grazing, 6% (20%) trees and 5% (1%) urban or infrastructure. Annual rainfall for the pilot areas ranges from 450 mm to 670 mm per year. A fixed budget of $400,000 was available for landholder payments.

Private landholders were engaged to supply EG&S through conservation contracts. Some of the goods and services produced from these contracts could be purchased by private firms (such as those required to offset carbon emissions) while others have public good attributes and are likely to be procured by an environmental agency on behalf of the public. An important aspect of the pilot was the use of biophysical models to provide information about the EG&S that are expected to be generated from landholder intervention. Each participating landholder received a site visit where they were informed about the EG&S that could be expected from a range of investments. In the pilot region, two forms of investment were common: revegetation of land which had been previously cleared, and restoration of habitat which had been degraded as a result of the impact of weeds, pests, stock and other influences. Within these two broad categories, many levels of investment were possible. The expected environmental benefit of each investment was estimated as the difference between the expected final state and the estimated initial state. Landholders were informed about the environmental benefits expected from their investment, were informed about the distribution of environmental outcomes across all bidders, but were not informed about the environmental outcomes of other individuals. Landholders were then asked to formulate a bid or payment needed to complete the investments indicated.

In formulating bids, landholders were required to estimate the return from carbon sequestration, based on a price of $12/tonne[1], and then to estimate the additional payment needed to make the investments proposed (generating public goods). An environmental authority received the bids and ranked them on the basis of the price per unit of public EG&S generated. All EG&S (both public and private goods) were procured through one contract with each landholder. The marginal bid was identified at the budget constraint and contracts were offered to all bidders below this price. The contracts were signed, after which the landholder made the investment needed to generate the outcomes specified. An initial payment was made, outputs observed (in the case of carbon) and a state-contingent payment was made. Progress payments for the habitat component of the contract were based on compliance with an input schedule.

Figure 2: Location of pilot



A sealed-bid, single round, price discriminating, budget constrained auction was employed to deal with adverse selection for EG&S with public good attributes (see Stoneham (2003)). Three changes were made to the allocation process to accommodate the more complex multiple-outcome problem. The first was to construct metrics for the public goods (habitat, water quality and salinity) as an

[1] The price of carbon was exogenously determined.

additive index. These are jointly supplied and need to be considered additively. For each public good domain of the environment, the expected change in state of the environment was normalised and represented as a percentage movement from the current, toward (away from) the pristine state[2]. The environmental benefit of each proposed contract was determined as the sum of the percentage movements for all public good domains. This is referred to as the Environmental Benefit Index (EBI). The second change was the development and use of sophisticated biophysical models employed to estimate the expected translation of landholder investment into environmental outcomes. Wu and Skelton-Groth (2002) developed an empirical model to demonstrate the extent of fund misallocation when jointly produced environmental outcomes are ignored. A simulation model was specifically developed for the pilot to map landholder investment to expected environmental outcomes by linking one-dimensional farming system models capable of simulating pasture, crops and trees with a fully distributed three-dimensional groundwater model. The model simulates daily soil/water/plant interactions, overland flow processes, soil loss, carbon sequestration and water contribution to stream flow from both lateral flow (overland flow and interflow) and groundwater discharge (base flow to stream). The model develops both a surface element network and a groundwater mesh based on unique combinations of spatial data layers. Typically, the spatial data necessary to derive the surface network includes: soil, topography, land use and climate. The groundwater model requires spatial data pertaining to aquifer stratigraphy, such as elevations of the top and basement of each aquifer, spatially varying aquifer properties and river/drainage cadastral information. This capability facilitated analysis of site specific investments (down to 50 by 50 metre resolution) or any aggregation of sites. Simulations predict both the expected outcomes and information about the probability function from which any outcomes will be drawn. Outputs include: soil/water balance (soil moisture, soil evaporation, transpiration, deep drainage, runoff, erosion); vegetation dynamics (crop/plantation yield, forest stem diameter, forest density, carbon accumulation); stream dynamics including stream flow, water quality and salt loads at a sub-catchment and catchment scale; and groundwater dynamics (depth to groundwater, aquifer interactions, groundwater discharge to land surface and stream at a sub-catchment and catchment scale) (see Beverly (2003) and Eigenraam (2006)).

The third change introduced was to inform bidders about the environmental goods and services offered by each landholder before bidding occurred. Based on laboratory experiments Cason, Gangadharan et al (2003) conclude that withholding

[2] Pristine is defined as the pre-European state of the landscape.

this information limits scope for landholders to extract information rents. Revealing this information could, however, improve dynamic efficiency if landholders then incorporate scarcity rents into land values.

4.1 Bids in the auction

Fifty-four bids were received in the auction. Figure 3 reports the frequency distribution of various levels of environmental benefit (EBI represents only the EG&S with public good attributes) for all sites assessed. Figure 4 reports the frequency distribution for various levels of carbon sequestration associated with individual bids. This information illustrates the heterogeneous nature of the environment with respect to the location and type of intervention, as discussed in section 2 of the paper. The auction also reveals the extent of heterogeneity with respect to bids expressed as a "supply price"[3] for additional units of EBI (see Figure 5). This distribution is weakly bimodal reflecting the higher cost and lower habitat gains from investments involving revegetation compared with habitat restoration.

Within the budget constraint a total of 357,186 EBI units were procured, consisting of 277,595 units of habitat improvement, 25,056 units of water quality improvement and 5,755 units of salinity control. As noted above, these units are additive representing the relative movement from the current environmental status toward a pristine state (as defined by the pre-European landscape). A total of 32 contracts were secured, representing management agreements over 257 hectares of land. Figure 6 illustrates the contribution of each of the public goods represented in the EBI. This figure shows that terrestrial habitat makes up most of the total improvement in environmental status. At the budget constraint, the marginal dollar invested by the environment authority translates into a 0.67% improvement in habitat, 0.08% improvement in water quality and 0.018% improvement in salinity. This suggests that investment in landscape change generates large changes in habitat improvement but relatively little improvement in either water quality or salinity control. This result can be largely explained by reference to section 2 where it was reported that the current stock of habit represents only 4% of the pre-European state.

A bid curve which ranks bids in order of bid prices is shown in Figure 7. The characteristics of the bid curve (many low cost bids but rising sharply thereafter) are consistent with the single outcome auctions run previously (Stoneham 2003). Funds available for the auction were allocated to contracts from left to right until the budget was exhausted. At the budget constraint of A$401,000, a bid price of

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[3] The term supply price is used recognising that there are information rents in landholder bids.

$18.26/EBI for the marginal unit of EG&S was observed. The highest bid received was $6050/EBI.

The performance of the auction with respect to adverse selection was assessed by comparing the budget outlays required to procure a given quantum of EG&S with those required when contracts are selected at random from the bid population of participants as represented in Figure 8. This analysis revealed that a saving of 30% was achieved by employing an auction to reveal landholder type compared with an institution that did not invest in revealing landholder type.

As noted above, landholders were informed about the quantity of EG&S (EBI) their bid was expected to generate and how their environmental service compared with other bidders. According to Cason, Gangadharan et al (2003) this would encourage bidders with high levels of environment to raise their bids to extract information rents. However, analysis of the composition of bids reveals that landholders with low offer prices (per unit of environmental outcome: ($/EBI)), tended to have high levels of environmental service as shown in Figure 9. Furthermore, the gross bid (in dollars) displays no trend across the entire range of offer prices ($/EBI). There may be several reasons for this observation. One is that the field pilot represents a one-shot game whereas the experimental analysis conducted by Cason et al involves repeated sessions. In the initial rounds of experimental sessions, it is commonly observed that several iterations of the trading are needed before bids reach equilibrium. From this it can be concluded that given further experience and information from real world auctions, fully informed landholders with higher levels of environmental benefits may raise their bids to capture more of the rents available. At the other end of the spectrum, those bidders with low environmental benefits would be constrained in lowering bids as individual participation constraints become binding.

As noted above, EG&S are jointly supplied such that procurement of additional units of public goods also generates additional units of private environmental goods and services. Carbon and water[4] are the two EG&S where tradeable permit markets could develop. One objective of the field pilot was to expose landholders to a "complete" set of missing markets for EG&S. Landholders were informed about the quantity of carbon likely to be sequestered from their investments and informed about a market clearing price for carbon ($12/tonne). They were then asked to nominate the additional payment required to change land use according to the management actions nominated in the contract. Figure 10 illustrates the quantity of carbon expected to be sequestered as additional EBI units (public goods) are procured. For contracts that supply additional units of EBI at low cost very little carbon

[4] In the Murray-Darling Basin of Australia a market for irrigation water already exists.

is sequestered. These contracts generally involve regeneration of existing habitat and the carbon sequestered from these contracts is not admissible under Kyoto arrangements. Revegetation, on the other hand, is recognised under Kyoto protocols but generates lower habitat improvement (the major component of the EBI) but provides carbon sequestration. At the budget constraint, an estimated 11,768 tonnes of carbon is expected to be sequestered if the actions specified in the contracts were implemented.

If it is assumed that landholders' participation constraints hold irrespective of the source of revenue (i.e. carbon emitters or a public authority purchasing public environmental goods) and that contracts jointly supply EG&S, it can be shown that an increase in the price of carbon will reduce the funds required to procure public goods. For a revenue constrained auction, data reported in Table 3 shows that as the clearing price of carbon rises, the number of contracts able to be funded from the environmental authority's fixed budget rises from 25 at $0/t to 41 at $20/t. These additional contracts only marginally increase the total quantity of public goods procured (EBI increases by 3% at a carbon price of $20/tonne) but there is a significant increase (91%) in the quantity of carbon generated. This result occurs because changes in the price of carbon precipitate reordering of the contracts from the environmental authority's perspective. Given the participation constraint, the unit price of public EG&S ($/EBI) will change as the price of carbon changes and according to the mix of public (as measured by the EBI) and private EG&S (carbon) offered by individual bidders.

Table 4 indicates that in a quantity constrained auction, the budget of the environmental agency required to procure public goods will be reduced as the price of carbon rises. The public funds needed to procure a given quantity of public goods (EBI) has been estimated to fall from $542,157 (at a price for carbon of $0/t) to $401,077 at $12/t and $302,657 at a carbon price of $20/t. This represents a saving of 26% and 44% respectively for the environmental authority.

5. Summary and conclusions

The way land is employed and managed has a significant impact on the environment. Based on analysis of one region it has been shown that landscape change reduces environmental amenity and increases the variability of services provided. It has been estimated that changes in the landscape over the last 200 years have: significantly increased the volume of stream flow; reduced the quality of water in rivers and stream; increased the area of dryland salinity marginally; and

Table 3: The impact of changes in the price of carbon: Revenue constrained auction

Price of carbon	$0/t	$12/t	$20/t
Total revenue required	$401,000	$401,000	$401,000
Number of contracts	25	34	41
Additional public goods (% increase in EBI units)	353191	360755 (2%)	364272 (3%)
Sequestration of carbon (tonnes of carbon)	10,078	11,768 (17%)	19,317 (91%)

Table 4: The impact of changes in the price of carbon: Quantity constrained auction

Price of carbon	$0/t	$12/t	$20/t
Public funds required	$542,157	$401,077	$302,657
Percentage saving	0%	26%	44%
Number of contracts	34	34	34
Public goods procured (EBI units)	360,755	360,755	360,755
Additional sequestration of carbon (% increase in tonnes of carbon)	0	0	0

caused a large decrease in the stock of terrestrial habitat. Analysis using biophysical models suggests that degradation of the environment can be reversed if private landholders invest in land use/management change. Two observations can be made about the way these investments transform into environmental outcomes. The first is the *heterogeneous* nature of the environment with respect to: land use; type of intervention/action; location of intervention/action; and the timing of outcomes. The second is that environmental outcomes are *probabilitistic* rather than deterministic because of the stochastic influences of weather, pests and other threatening processes.

While private landholders are rewarded for investment in commercial activities, such as commodity production, the economic system lacks incentives to reward investment in the environment. It is widely understood that markets fail because some domains of the environment display public good attributes and society lacks the mechanisms needed to make collective decisions about the social preferences for public goods. Even if this information were available, it is now understood that information asymmetry on the supply side also causes these markets to fail. Information problems are expressed as adverse selection and moral hazard and if not addressed will prevent transactions from occurring between landholders able to competitively supply EG&S and firms or organisations willing to pay for these goods and services.

The pilot reported in this paper recognised that most investments in land use change/management generate multiple environmental outcomes. Some of these EG&S (eg. carbon and irrigation water) are able to be sold to private firms through tradeable emission markets while others have public good attributes including water quality, habitat and groundwater accession. In the pilot, landholders were exposed to an exogenously determined price of carbon and an environmental agency was allocated a budget to procure EG&S with public good attributes. Adverse selection was addressed by auctioning conservation contracts but a substantial investment was needed prior to the pilot to develop biophysical models and biological information systems to meet specific information deficiencies. A sealed-bid, single-round, price discriminating, budget constrained auction format was employed. Bidders were informed about the quantity of EG&S offered by their investments and their contribution relative to other bidders.

The first observation to be made from the pilot is that transactions to supply EG&S were facilitated by the institutional framework developed. These transactions were made possible by designing and creating new institutions that reveal relevant information, process this information in ways that introduce competition into the environment sector, and by designing incentive compatible supply contracts. These will be important elements of environmental programs that have an economic efficiency objective. When private landholders are exposed to these new institutions, they are required to make tradeoffs between investment in commodity production and investment in supplying different classes of EG&S. Because of the private and heterogeneous nature of information and incentives not to reveal this information, landholders are best placed to make these tradeoffs – not central planning authorities. It has been estimated from the pilot data (under a fixed outcome objective) that a 30% saving in the procurement budget could be made by auctioning conservation contracts to discover landholder "type" compared with a mechanism that does not address adverse selection (eg. a random draw).

This finding has important implications for the policy mechanisms employed in many countries to procure environmental outcomes from private landholders. Planning and legislative solutions require all landholders, irrespective of whether they are high or low cost providers, to undertake investments in conservation. Excluding problems that require full enrolment, centralised approaches will raise the cost and diminish economic efficiency of environmental programs. For the same reasons, other policy mechanisms, such as fixed-price grants and simple incentive schemes will display similar efficiency and cost-effectiveness problems. Unless adverse selection is specifically addressed, it is landholders who hold market power in these transactions because they have private information about the cost of land use change/management. The government environmental authority will come off second best in this transaction. A number of studies confirm this contention, reporting the payment of excessive information rents to landholders. By investing in information systems (biophysical models) and new institutions the purchaser can reduce, but not eliminate, these information rents and so claw back some economic efficiency gains. As noted by Laffont (2002) there is some optimum where the marginal cost of further reducing information rents equates to the marginal efficiency gains. The adverse selection problem is less important where landholders transact EG&S with private good attributes such as through a tradeable emission permit scheme. In this institution landholders are price takers and will self-select into supply contracts according to type. Moral hazard is a more important design problem in this case than adverse selection.

Landholders in the auction were provided with full information about their absolute and relative provision of EG&S with public good characteristics. Previous experimental analysis suggests that this strategy would encourage landholders to raise bid prices. However, analysis of bid data failed to detect any systematic rent seeking behaviour by bidders. While this finding is at variance with the experimental finding of Cason, Gangadharan et al (2003) this difference in behaviour may arise because the pilot involved a one-shot game compared with multiple rounds of the market experienced by bidders in the experimental situation.

The pilot provided some insights into the moral hazard problem relevant to the design of conservation contracts. Although economic theory clearly suggests that incentive compatible contracts will involve the landholder sharing some of the risk involved in achieving environmental outcomes, this has proven difficult to achieve in practice. Four problems have been identified. For some EG&S, such as water quality, the observed environmental outcome arises from the combined actions of a team of landholders. Different incentive structures will be needed to deal with the free-rider problem in this situation. A second problem arises because each investment by landholders has been shown to generate multiple outcomes. While a simple solution to this could be to pro-rata incentives according to the ratio of different EG&S generated, it is not clear whether the incentive effects of this approach are efficient. A third problem involves the long time scales (up to 200 years with groundwater systems) between investment and environmental outcome. Over such long time scales, the incentive effects of contracts will be lost. In this event, measures of outputs, such as tree growth, could be used as the signal for incentive payments to landholders. Biophysical modelling could assist in identifying appropriate output signals and the translation between outputs and outcomes. The final problem with contract design arises because in the initial periods of a contract, many landholders do not have technical knowledge about how inputs transform into environmental outcomes. While they are generally efficient at transforming inputs into commodities, they are often unfamiliar with the production of EG&S, at least in the early stages of the contract. One proposed solution could be to define two stages of the contract, the first where landholders are provided with an incentive structure that rewards learning about environmental production, and a second phase that includes incentive compatible bonuses for outcomes. All of these contract design problems warrant further research.

The pilot also provided some insights into the way markets for different EG&S interact. Holding the participation constraint fixed, it has been shown that varying the price of carbon (an intersecting market because of the joint supply observation) has a significant effect on the allocation of land. The ranking of contracts changes markedly as the price of carbon is altered. There are two important implications of this finding. The first is that there will be economic efficiency implications where markets for some EG&S are missing. Environmental programs that do not take all EG&S into account could sponsor changes to the landscape that cause environmental decline. Tree planting schemes could arguably cause streams to dry-up, increasing the pressure on aquatic species and reducing the value of irrigation farmers' property rights for water. Where markets for some domains of the environment do not exist, it would seem appropriate to impose a tax or regulation to prevent unwanted environmental outcomes, but only as a second-best policy solution. A second implication of the observed interaction between markets for different EG&S is that there are significant cost savings to be made by environmental authorities as a result of the multiple outcomes obtained from land use change. Sequestering carbon, for example, automatically generates a bundle of EG&S with public good attributes. For a fixed outcome of public EG&S, it has been estimated that a saving of 26% could be expected by the environmental agency if the price of carbon were to rise from $0/t (no market) to $12/tonne.

Some environmental goods, such as water quantity, tend to be negatively correlated with vegetation related EG&S. Although the pilot was conducted in a region that is not a recognised catchment for irrigation water, the implications of incomplete markets for EG&S are clear. Where irrigators hold property rights for water, the interaction between landscape change and water markets will be profound.

Although the pilot focused on the supply side, it does provide some information relevant to the demand side of the market. For the pilot region, for example, it can be shown that at the margin, another dollar allocated to the environmental authority could provide: a) 37 units of habitat or one unit of salinity control; b) 4.5 units of water quality control or one unit of dryland salinity; or c) 8.7 units of habitat or one unit of water quality improvement. This information would improve the "information space" in which to elicited information about willingness to pay for additional unit of the environment. It does not, however, resolve the information and aggregation problems that persist on the demand-side of the market for environmental goods and services.

Figure 3: Distribution of environmental benefits

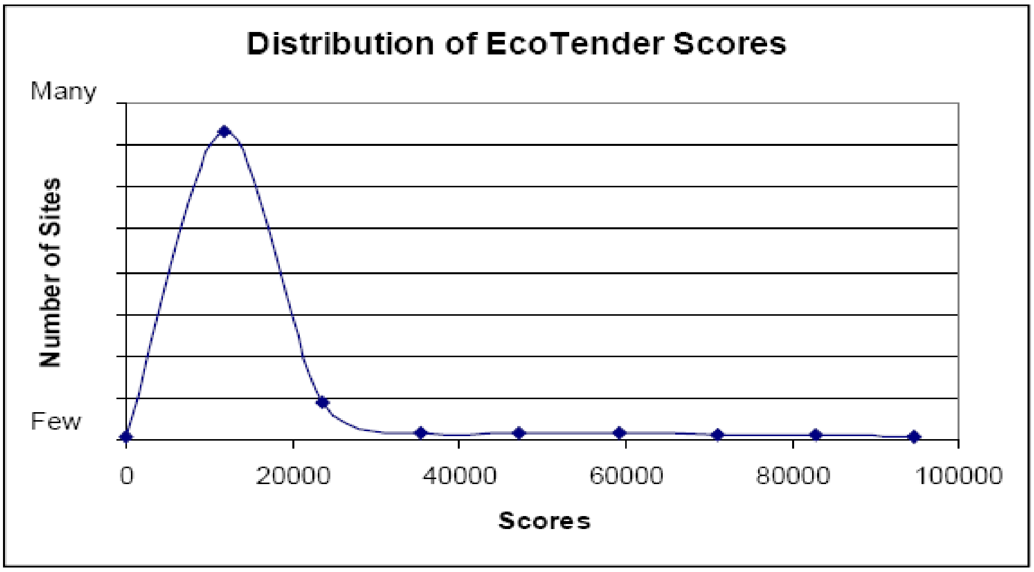


Figure 4: Distribution of carbon sequestration

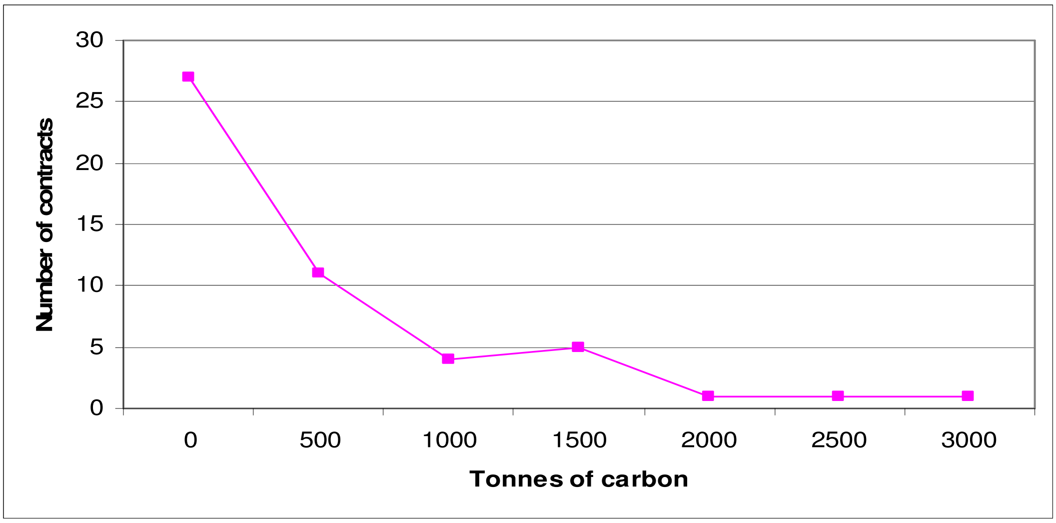


Figure 5: Distribution of bids expressed as a supply price

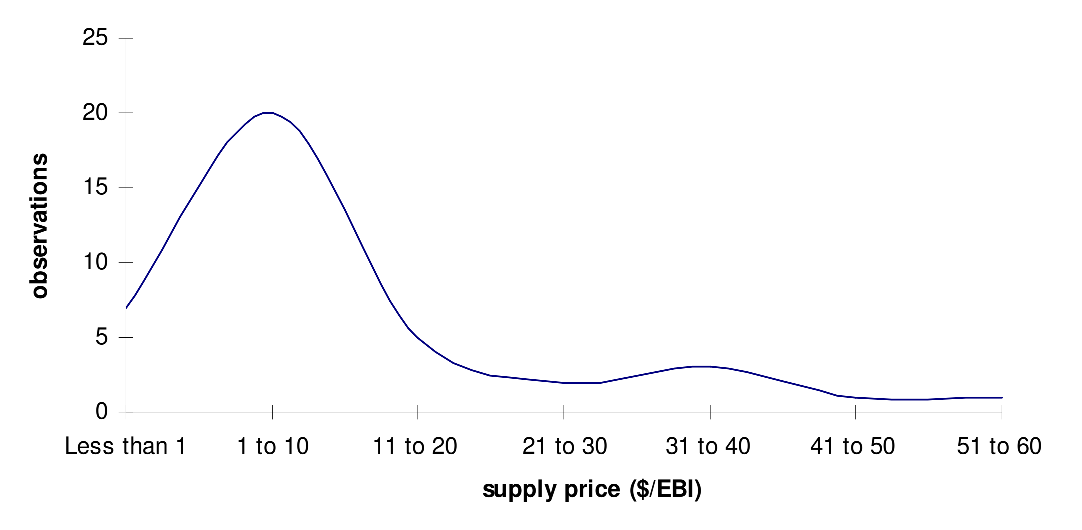


Figure 6: Environmental goods and services offered

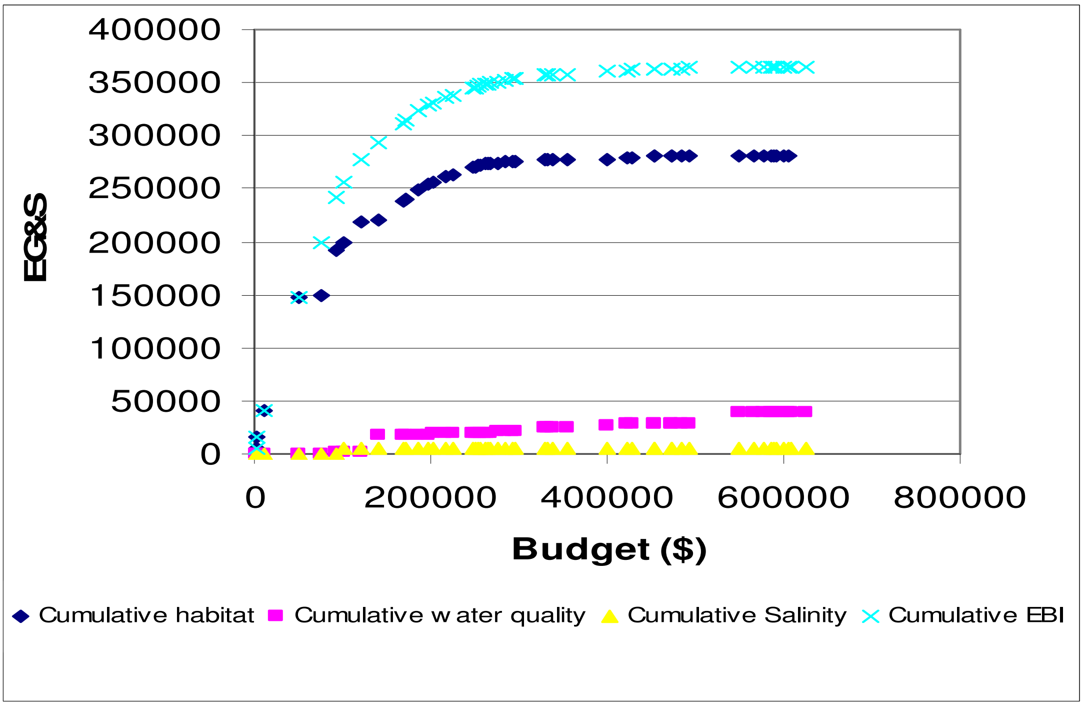


Figure 7: Bid curve

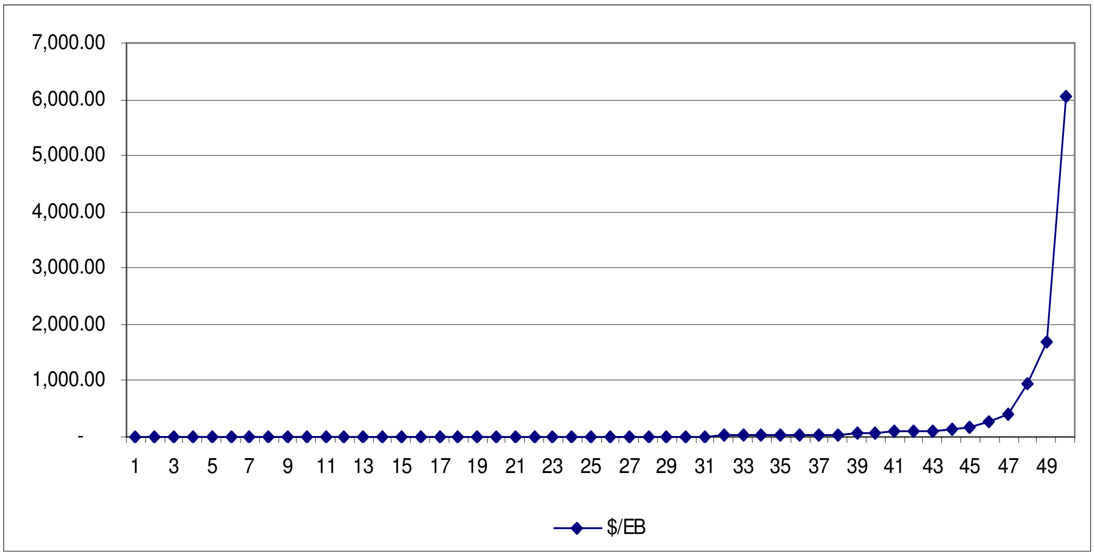


Figure 8: Adverse selection

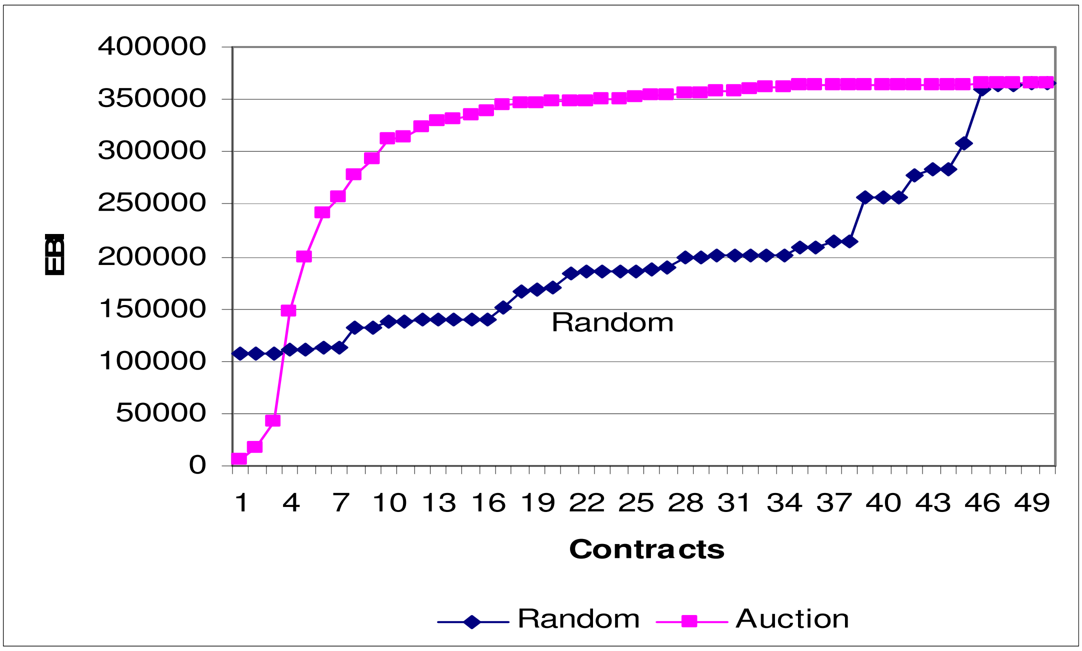


Figure 9: Factors influencing bid price

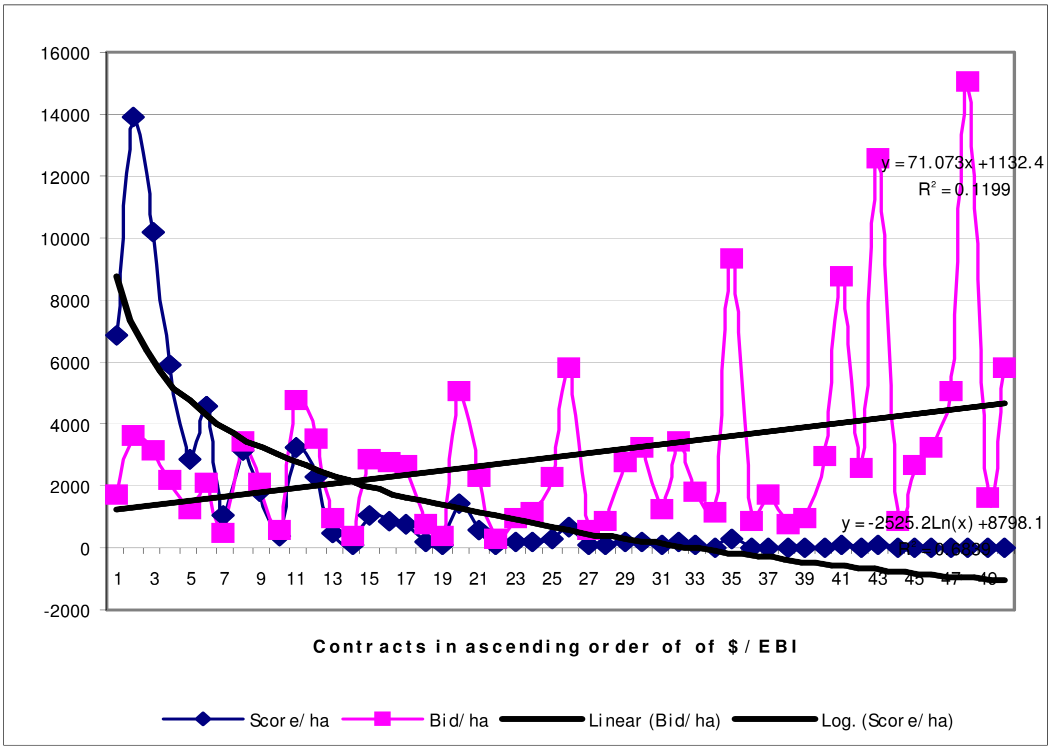
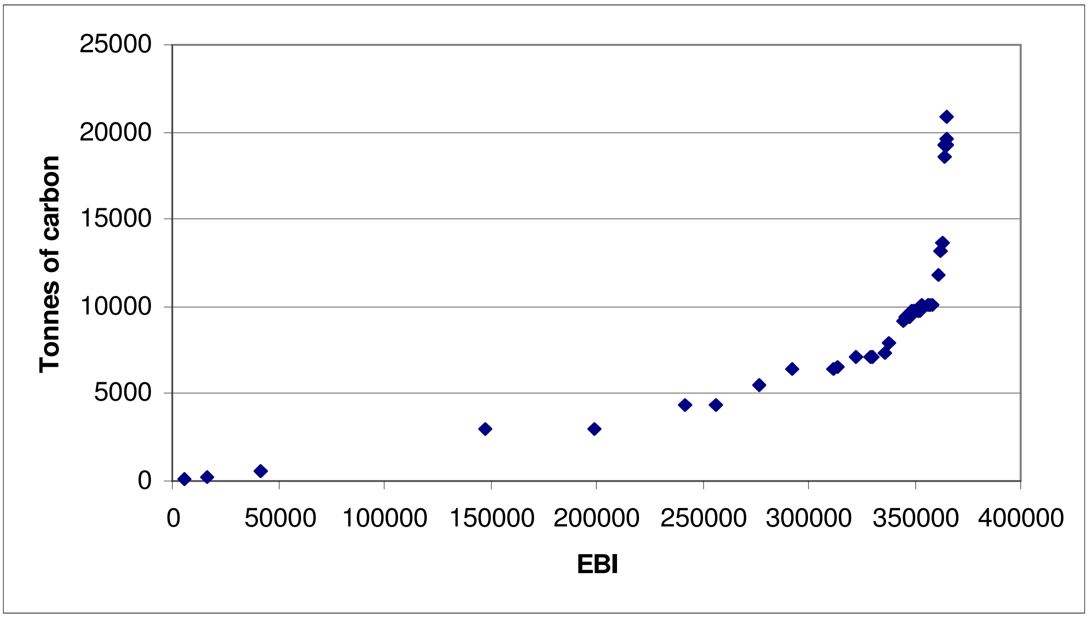


Figure 10: Carbon sequestration and EBI



APPENDIX I: Adverse selection and moral hazard

A formal representation of the general principal-agent problem has been developed in Laffont (2002) and a specific application of this framework to the procurement of EG&S from private land can be found in Anthon (2006). In summary, the agent *A* undertakes investment $(I_{t,l})$ (*t* denotes the type of investment and *l* the location of investment) which generates a change in the state of the environment *S*. Environmental states can be represented as $S(I_{t,l}, e)$ where *e* is a random variable and $\partial S / \partial I \leq 0$. Landholders could invest $\overline{I}$ (high) or $\underline{I}$ (low) generating a new state of the environment defined as a probability function F(S). For simplicity, only two states are considered: S^L (low state) and S^H (high state) which characterise the new probability function. Only a fraction of landholders ν have a high probability $\overline{\alpha}_i$ of achieving the high state S^H from $\overline{I}$ while the remainder $(1-\nu)$ will have a lower probability $\underline{\alpha}_i$ of achieving S^H from $\overline{I}$. For the same investment, landholders may also generate S^L with a probability of $(1-\overline{\alpha}_1)$ or $(1-\underline{\alpha}_1)$. Similarly some landholders making a low investment $\underline{I}$ will achieve S^H with a probability of $\overline{\alpha}_0$ and $\underline{\alpha}_0$ according to type or will generate S^L with probability $(1-\overline{\alpha}_0)$ and $(1-\underline{\alpha}_0)$ according to type.

Expected social welfare can be denoted by:

$$W = (1-\nu)[\underline{\alpha}_0(V^H - \lambda \underline{t}^H) + (1-\underline{\alpha}_0)(V^L - \lambda \underline{t}^L) - \underline{I}] + \nu[\overline{\alpha}_1(V^H - \lambda \overline{t}^H) + (1-\overline{\alpha}_1)(V^L - \lambda \overline{t}^L) - \overline{I}]$$

which represents the expected net social benefit of the environmental goods and services *(V)* after accounting for transfers *(t)* to landholders to reward investment and the social cost of public funds (λ).

Adverse selection - Under incomplete information, a first-best solution is not possible because agents have some market power that derives from the information they hold about their costs and technology. As long as the principal insists on a level of output of EG&S from the inefficient type, the principal must give up a positive rent to the efficient agent who can mimic an inefficient agent with respect to marginal cost. Following Anthon (2006) and Laffont (2002), the incentive compatibility constraints in the pure adverse selection problem are:

$$\overline{\alpha}_1 \overline{t}^H + (1-\overline{\alpha}_1)\overline{t}^L - \overline{I} \geq \overline{\alpha}_0 \underline{t}^H + (1-\overline{\alpha}_0)\underline{t}^L - \underline{I}.$$

$$\underline{\alpha}_0 \underline{t}^H + (1-\underline{\alpha}_0)\underline{t}^L - \underline{I} \geq \underline{\alpha}_1 \bar{t}^H + (1-\underline{\alpha}_1)\bar{t}^L - \bar{I}$$

The high probability agent must be rewarded for the high state but the low probability agent must not be rewarded for the high state as this would give the high probability agent an incentive to pass as a low-probability agent $\underline{t}^H \leq t^L$. If the low state is achieved payment cannot be higher than for the high state as this would give perverse incentives (i.e. $\underline{t}^H = \underline{t}^L$). The *participation constraint* under the incomplete information scenario then becomes:

$$E(\bar{\pi}) = \bar{\alpha}_1 \bar{t}^H + (1-\bar{\alpha}_1)\bar{t}^L - \bar{I} \geq 0 \qquad \overline{PC}$$

$$E(\underline{\pi}) = \underline{t} - \underline{I} = 0 \qquad \underline{PC}$$

This reduces the *incentive constraints* to: $\bar{\alpha}_1 \bar{t}^H + (1-\bar{\alpha}_1)\bar{t}^L - \bar{I} \geq \underline{t} - \underline{I} = 0$; and

$$\bar{\alpha}_1 \bar{t}^H + (1-\bar{\alpha}_1)\bar{t}^L - \bar{I} \geq \underline{t} - \underline{I} = 0$$

$$0 = \underline{t} - \underline{I} \geq \underline{\alpha}_1 \bar{t}^H + (1-\underline{\alpha}_1)\bar{t}^L - \bar{I}$$

The adverse *selection constraints* become:

$$\bar{\alpha}_1 \bar{t}^H + (1-\bar{\alpha}_1)\bar{t}^L \geq \bar{I} \qquad \overline{AD}$$

$$\underline{\alpha}_1 \bar{t}^H + (1-\underline{\alpha}_1)\bar{t}^L \leq \bar{I} \qquad \underline{AD}$$

This suggests that the expected payment to the high–probability agent has to be larger or equal to his investment $\bar{I}$. In this case the principal will need to pay more than opportunity costs for the high probability agent to participate but the expected payout to the low-probability agent posing as the other agent has to be smaller than $\bar{I}$. Where the agent takes all of the risk, the optimal contract for the higher type will be to pay zero if the low-state is achieved and a payment higher than the investment if the high state occurs. Alternatively, if the principal takes all the risk, the optimal contract is to pay the same transfer whatever the final state.

Moral hazard - Moral hazard occurs when there is uncertainty in the way that the effort/inputs of agents (disutility for the agent) translate into outcomes (the objective of the principal). This uncertainly arises because: a) the principal is interested in the result (in this case the environmental outcomes), but the agent may not be; b) the principal is not directly interested in effort exerted by the agent but the agent is because effort translates into additional costs; and c) there is a connection between increased effort and increased outcomes (see Macho-Stadler (2001)). Laffont (2002) notes that this uncertainty of supply "is central to the contractual design problem with respect to moral hazard. The principal wants to induce the agent to high effort despite the impossibility of directly conditioning the agent's reward on his action".

In the pure moral hazard case (no heterogeneity between agents) but where the investments made by landholders are non-verifiable, the principal will prefer high investments in the production of EG&S. The expected social welfare can be expressed as:

$$W = \alpha_1 (V^H - \lambda t^H) + (1-\alpha_1)(V^L - \lambda t^L) - \overline{I}$$

The participation constraint as for the adverse selection case is:

$$\alpha_1 t^H + (1-\alpha_1) t^L - \overline{I} \geq 0 \qquad \text{(PC)}$$

and an additional incentive constraint for moral hazard is added to ensure that the expected return to the high investment type has to be larger than the expected return of the low investment type:

$$\alpha_1 t^H + (1-\alpha_1) t^L - \overline{I} \geq \alpha_0 t^H + (1-\alpha_0) t^L - \underline{I} \,.$$

This is rewritten as:

$$(\alpha_1 - \alpha_0) t^H + (\alpha_1 - \alpha_0) t^L - \Delta I \geq 0 \qquad \text{(MH)}$$

where $\Delta I = \overline{I} - \underline{I}$

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