Electronic BushBroker exchange: Designing a combinatorial double auction for native vegetation offsets

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ABSTRACT

In Victoria, Australia individuals or firms wishing to proceed with development that involves the clearing of native vegetation are required to obtain an offset to replace the vegetation destroyed. This paper focuses on the design and testing of the electronic BushBroker exchange and the evaluation of alternative market institutions, while briefly describing the metric, trading rules and contracts used in the Victorian native vegetation offset scheme. The purpose of the design is to facilitate efficient trades of offsets between developers and landowners and to overcome the complexities inherent in the native vegetation market. Four different types of policy and economic complexities were identified: policy, transaction, strategic, and time complexities. The market design recommended includes 'smart market' features (optimization constrained by the offset trading rules), combinatorial bidding preferences (or package bidding) on both the buyers' and the sellers' side, and strategic tools (including search and query functions and 'market making'), to encourage competitive trading activity. This paper seeks to elucidate the rationale behind these design features. We use two types of tests to assess the performance of the system. A series of experimental tests were used to evaluate the software performance, usability and to elucidate specific bidding behaviour and to assess efficiency. Simulations using actual data were employed to test the robustness of the system by increasing the complexity and scale of the data.

Keywords: native vegetation, offsets, biodiversity, double auction, combinatorial auction, experimental economics, market design

JEL Classifications: C90, D44

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1. INTRODUCTION

Since 1750, an estimated 66% of Victoria's native vegetation has been cleared as a result of growth and economic development – the highest percentage of any state in Australia. Of the remaining 34%, it is estimated that 7.4 million hectares are located on public land and 1.1 million hectares are found on private land (DNRE, 2002). Private land is home to around 30% of Victoria's threatened species habitat, and in many locations this includes large trees. Large trees are an important nesting habitat for forest animals, and their relative concentration on private land enhances their conservation significance (DSE, 2006).

The extent of native vegetation clearance varies widely around the state. Accessible and relatively fertile landscapes that were developed for pastoral and agricultural activities and urban expansion have been most affected. In one extreme example, the Victorian Volcanic Plains in the south west of the state have been 94% cleared (DNRE, 2002).

While it is important to set inspirational goals, such as "no net loss" of native vegetation , moving away from objectives and towards designing and implementing a market institution is difficult. The design problem becomes even more troublesome when key information (e.g. as the public benefit of biodiversity conservation) is not easily observable or is hidden (e.g. the private costs of improving habitat and the private benefits of clearing habitat).

The traditional approach has been to treat negative environmental impacts, including native vegetation clearing, as externalities. One consequence of the traditional approach is that native vegetation had no tangible monetary value. Consequently, native vegetation was not priced into transactions and economic calculations. This led to an inevitable conflict between economic development and environmental conservation and narrowed-down the range of policy responses that might be employed. Some government policies such as zoning, codes of practice, and planning provisions intend to incorporate environmental (public) preferences into the decision making. Other policies, such as taxes, penalties in lieu payments intend to approximate or 'mimic' economic values of the environmental goods. These policies, however, fail to address the problem of finding the socially desirable *and* economically viable *'trade-off'* between environmental conservation and economic development. The key problem is that traditional policy mechanisms do not invest in processes to reveal and incentives to act on information needed to efficiently allocate resources between production and conservation. The use of ineffective and inefficient policy mechanisms is one of the key causes of the world-wide environmental crisis caused by excessive clearing of native vegetation (see Millennium Ecosystem Assessment, 2005).

Following developments in economic theory, experimental economics (Plott, 1982; Smith, 1982) and in science a new policy mechanism design methodology has evolved opening-up the prospect of creating new institutions that mimic the way markets introduce incentives into resources allocation processes. This approach employs market mechanisms to reveal privately held values associated with public goods (e.g. Shogren et al., 1999; Tietenberg, 2000). For example, under a cap-and-trade permit system the regulatory authority sets a cap on environmental resource use (e.g. pollution permit, fishing quota) and allows the market to ration access to the resource so that the resulting pattern of use minimizes the cost of achieving the environmental objective (Montgomery, 1972). Transferable development rights (TDR) and tradable land-use rights (TLR) programs are the biodiversity conservation analog of tradable permit programs.

Vegetation offset schemes are more similar to the baseline-and-credit permit systems. Any clearing that decreases the vegetation level below baseline requires a credit (offset) to be purchased. Credits can be generated in a number of ways. For example, by improving the condition and conservation status of the vegetation on their land, a landowner can receive credits. Complex trading rules govern the transactions in the vegetation offset market in order to ensure equivalency in the biodiversity conservation value of the vegetation cleared and that used as an offset. The prices at the offset market will allow the incorporation of the biodiversity value into economic cost-benefit calculations. Economic theory dictates that the price of vegetation offsets in areas with scarce biodiversity values will be higher (increasing the cost of development in the area) while the price of vegetation offsets representing relatively abundant biodiversity values will be lower (keeping the cost of development in the area relatively low). The native vegetation offset policy allows the decisions concerning economic development to be made in conjunction with environmental conservation. The policy allows ‘trade-offs’ to be made between economic development and environmental conservation by revealing the private and public benefits and costs of these decisions.

Key features of an offsets scheme include:

- *regulation* that requires parties that create an environmental impact to obtain an offset
- a *metric* to define property rights and measure/differentiate the environmental goods being traded
- *trading rules* that ensure offsets will meet environmental objectives
- *contracts* designed to ensure that the environmental offset is delivered over time
- a *market mechanism* that maximises economic efficiency and overcomes the policy and economic complexities
- a *recording system* that documents ownership and disposition.

This paper's emphasis is on the design of the electronic BushBroker exchange, a market system designed to facilitate efficient trades between buyers and sellers of native vegetation offsets and to overcome the complexities inherent in the native vegetation market.[1] The above key features of an offsets scheme are briefly described

The important philosophy embedded in the 'market-based' approaches is the objective of maximising economic efficiency – the same objective that exists in autonomous market systems. Designing policy mechanisms to explicitly achieve economic efficiency creates a discipline in policy design that has been lacking in environmental policy programs. Two kinds of tests are employed to design and refine a market for native vegetation offsets. A series of experimental tests were used to evaluate the software performance, usability and to elucidate specific bidding behaviour and to assess efficiency. In addition, simulations using actual data were employed to test the robustness of the system by increasing the complexity and scale of the data. We also evaluated the relative efficiencies of the market design under four different institutional arrangements.

2. LEGISLATIVE BACKGROUND OF NATIVE VEGETATION MANAGEMENT IN VICTORIA

Victoria's *Native Vegetation Management Framework* (DNRE, 2002) established the strategic direction for the protection, enhancement and revegetation of native vegetation across Victoria. It set the goal of achieving "a reversal, across the entire landscape, of the long-term decline in the extent and quality of native vegetation, leading to a net gain."[2] The framework defines a sequential approach to clearing and planning permit decisions, namely to "avoid, minimise and offset". Since the 1987 introduction of *The Planning and Environment Act*, individuals or firms

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[1] There are several initiatives for TDR, TLR and biodiversity offset schemes around the world. For example, there are approximately 60 TDR programs in the United States, Successful implementation, however, has not been widespread (Johnston and Madison 1997; AFT, 2001; Messer, 2007). In many programs bilateral negotiations take place either between buyers and sellers or a government representative is expected to act as a broker by bringing parties together. Negotiating with so many parties comes at a high transaction cost. Messer (2007) finds that to overcome high transaction costs a carefully designed market is needed. In their theoretical paper, Field and Conrad (1975) argue that the benefits of a TDR program will be realized only if there is a "well organized auction" where the transaction costs between the buyers and sellers are as low as possible. McConnell et al. (2003) list the lack of information on previous prices as another reason for reduced market activity. Messer (2007) argues that in an ideal world, "…the government's role should be limited to the planning efforts and delineating the sending and receiving zones. A market system should take over once the rules have been established." However, the author concedes that in reality, there is a role for the government to design a market structure to ensure low transaction costs and that the transactions are "conducted in a transparent, expedient, and information rich setting."

[2] There are two main market-based instruments in Victoria in the area of native vegetation. The BushTender program procures biodiversity value (measured in habitat hectare and environmental benefit index) leading to a 'net gain' in biodiversity. The BushBroker program requires developers to offset the vegetation destroyed, and aims to

wishing to proceed with development involving the destruction of native vegetation are required to obtain a *permit* through the relevant planning authority. The native vegetation management framework extends the existing permit obligation by requiring that an *offset* to be procured to replace any vegetation destroyed.

Whilst native vegetation offsets may be created in several ways, they are generally supplied by private landowners who choose to divert resources from activities such as livestock and crop production, in order to increase the stock and quality of native vegetation.[3] Behind each supply pathway is a production function that converts inputs of land, labour and capital into native vegetation outputs.[4] Landowners hold private information about their opportunity costs of providing native vegetation offsets. These opportunity costs include forgone revenue from alternative uses of the land and shape the minimum revenue required by landowners to divert resources from their regular activities to increasing the stock of native vegetation in the form of offsets.

The demand side of the market for native vegetation offsets is represented by developers. By law, developers are required to procure native vegetation offsets for vegetation destroyed. Developers hold the private information about their willingness to pay for offsets that is derived from final goods markets such as housing, road and rail infrastructure etc.

3. PROPERTY RIGHTS: NATIVE VEGETATION METRIC

Australia has highly varied native vegetation. A number of quantitative techniques have been developed in Victoria that describe the characteristic of native vegetation and its interaction with the broader environment. The environmental metric used by BushBroker incorporates data on the quantity, quality, type, significance level and location of the native vegetation. Quantitative evaluation is necessary to predict the consequences of land change on biodiversity so that proposed offsets accurately compensate any loss of biodiversity incurred. The information provided by the metric allows ecologists to make an informed decision in determining where,

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achieve 'no net loss' in biodiversity. For further information on the BushTender program, see Stoneham et al. (2003).

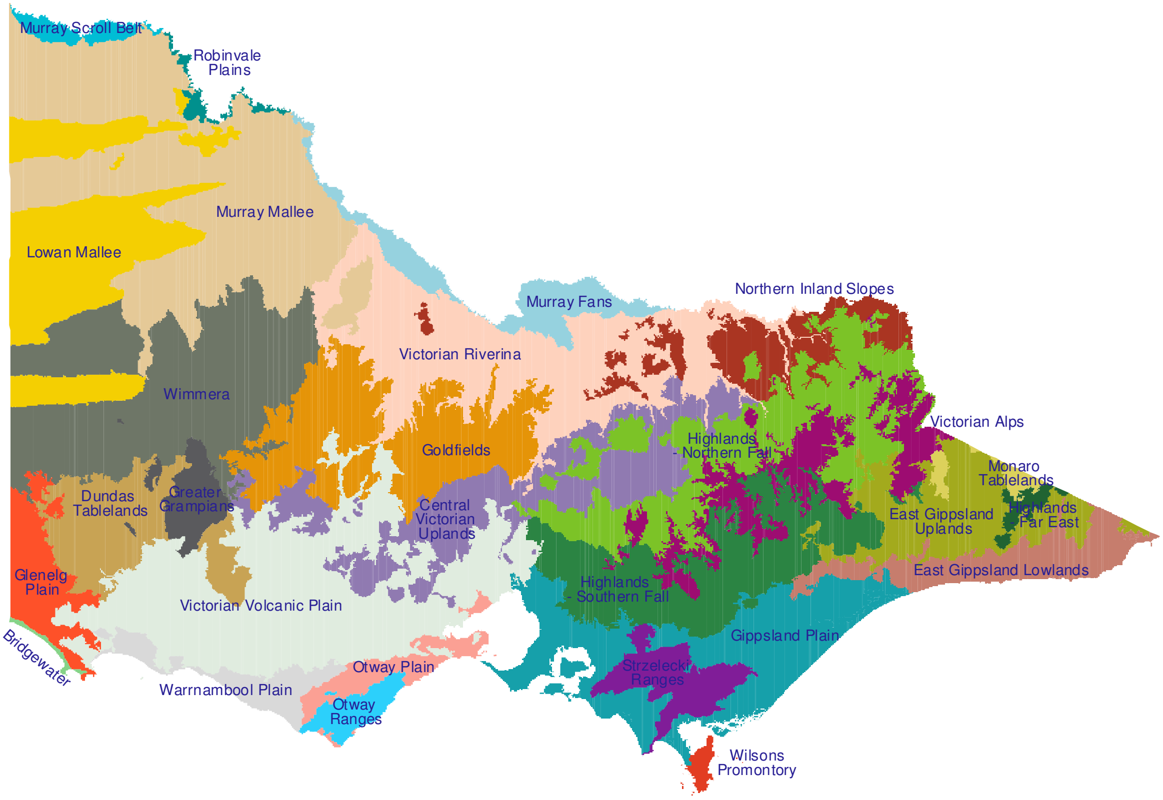
[3] Native vegetation offsets may also be supplied on public land by going beyond the required vegetation management level. Also, donating freehold land to the Crown for a Park or Nature Conservation Reserve or secure Municipal Reserve managed for conservation is also another way to create offsets but as such donations are rare and do not require a trade, they are outside the scope of the current paper.

[4] For example, grasslands could be managed in one way to generate animal products but this degrades the stock of native vegetation. Managed in another way, grasslands can generate increases in the stock of vegetation but there are costs associated with this approach (e.g., costs of fencing to control access by stock, weed control, labour and inputs and the costs of foregone income from grazing).

how much, and what type of offset is required by those applying for a permit to clear native vegetation.[5]

Victoria is divided into 28 bioregions (bio-geographic areas) that capture the patterns of ecological characteristics in the landscape, see Figure 1. Vegetation in Victoria is further classified into over 300 plant (floristic) communities, termed ecological vegetation classes (EVCs). Each EVC represents plant communities that occur in similar environment types, and tend to show similar ecological responses to environmental disturbance factors such as wildfire. Depending on their conservation status (rare, endangered, threatened, etc.) EVCs are aggregated into one of four *significance levels*: very high, high, medium, and low.

FIGURE 1: BIOREGIONS IN VICTORIA



Techniques have also been developed that evaluate the quality and quantity of native vegetation. For patches of remnant vegetation, Parkes et al. (2003) developed the *habitat hectare* environmental metric. The habitat hectare is a site-based measure of quality and quantity of native vegetation that is assessed against a benchmark for the specific EVC. The habitat hectare

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[5] Chomitz et al (2003) distinguishes two kinds of policy makers according to their views on how far down the hierarchy to go in determining equivalence. “Lumpers” favor equivalence within high level classifications, allowing substitutability among all neotropical forests, for instance. “Splitters” favor restricting forest substitutability to finer classifications; for instance, particular types of neotropical forests (e.g., moist neotropical rainforests), forest subtypes based on unique assemblages of species and communities (e.g. the Atlantic Rainforest of Brazil), forests within particular watersheds, or at the limit, forests within a particular microwatershed of a few thousand hectares. Choice of the appropriate level involves a trade-off between the efficiency gains offered by a broad classification, and the potentially greater representation of biodiversity offered by a fine classification.

measures the quality of vegetation communities, rather than the quality of individual species, thereby capturing how a site compares to its virgin state. Old trees provide important habitat for animals in Australia, especially those with hollows. Offsetting the biodiversity loss resulting from the clearing of large old and medium old trees has been given special attention in Victorian native vegetation offset scheme. The loss of *scattered trees* is expressed in terms of the number of *large old trees* and *medium old trees* lost, defined in relation to the relevant benchmark specific to the EVC. The loss of *trees within a remnant patch* is conversely expressed in terms of the number of *large old trees* and the number of habitat hectares lost in recognition of the synergistic relationship between trees and the remnant patch they are part of.

There are ten measures of habitat quality (e.g., canopy cover, understorey strata, lack of weed, organic litter, etc) that are scored and weighted for each site. Habitat hectare (HH) is the product of the quality measure (habitat score) and the area of native vegetation:

$$\text{Habitat Hectare} = \text{Habitat Score} \times \text{Area}$$

One hectare of pristine vegetation is equivalent to one habitat hectare, whereas one hectare of degraded vegetation converts to a fraction of a habitat hectare, the actual figure dependent upon the extent of degradation.[6]

4. TRADING RULES: 'LIKE-FOR-LIKE' CRITERIA

Specific rules also exist to govern the exchanges made in offset transactions. These rules have been documented in *Victoria's Native Vegetation Management – A Framework for Action*

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[6] For example, if an unaltered area of natural habitat is at 100% of its natural quality, then one hectare of such habitat will be equivalent to one habitat hectare. That is, the quality multiplied by the quantity. Ten hectares of this high quality habitat would be equivalent to ten habitat hectares. If an area of habitat had lost 40% of its quality (say by way of weed invasion and loss of understorey), then one hectare would be equivalent to 0.6 habitat hectares, ten hectares would be equivalent to six habitat hectares.

There has been considerable debate around the habitat hectare measure as policy or management tool. Parkes et al. (2003) emphasize the strength of habitat hectares as an information exchange tool and stress that drawbacks of simplifying concepts from a research tool viewpoint convert to gains when it helps to "bridge the large gap between landowners and local resource managers and the complex concepts and methods of quantitative ecology". Gibbons and Lindenmayer (2007) highlight the importance of the habitat hectare as "a currency that is fungible", and that general functionality is enhanced by aggregating environmental components into a single metric. McCarthy et al. (2004) recognize that the habitat hectares approach aims to be "rapid, objective, reliable and repeatable". However, the authors criticise the tool, its components, and the comparison with a single benchmark. Parkes et al. (2003) emphasise the trade-offs between simplicity, accessibility, and usability to the technical benefits of a precise research tool that tackles more complex attributes but requires significant resources and training. The paper by Tolsma and Newell (2003) describes the further testing of the habitat hectares technique, and suggests ways in which the technique could be further refined to increase its utility, objectivity and reliability. The detailed discussion of scientific debate around the habitat hectare measure is outside the scope of this paper.

(DNRE, 2002) and are referred to as the *like-for-like* requirement. The ‘like-for-like’ criteria are effectively trading rules that require the vegetation gains from an offset to be *commensurate* to the vegetation loss in terms of conservation significance, quality, and habitat/vegetation type. There are two sets of rules, one for remnant patches and one set for trees (which may be within a remnant patch or alone as scattered trees as described above). The simplified version of these rules is reproduced in Table 1 and Table 2. (For the more extensive version see DNRE, 2002.)

In general, offset transactions that involve high conservation significance are based on conservative exchange rates using a precautionary principle whereas those involving low conservation significance are based on a one-for-one exchange. There are also *spatial restrictions* (bioregion constraint) and *quality restrictions* (habitat score constraint) on offset transactions. For example, the ecosystem and habitat value of a cool temperate rainforest in the Otway Ranges is not substitutable with a Snowpatch Herbland in the Victorian Alps. In certain circumstances, however, clearing Heathy Dry Forest in the East Gippsland Lowlands may be offset by the protection of Shrubby Dry Forest located also in the East Gippsland Lowlands. Revegetation sites may also be used to create native vegetation offsets but there are restrictions when and to what extent revegetation sites can be used as offsets.

TABLE 1: REMNANT PATCH OFFSET REQUIREMENTS

CONSTRAINTS	SIGNIFICANCE LEVEL			
	Very high	*High*	*Medium*	*Low*
Habitat hectare constraint	Habitat hectare of offset has to be at least 2x the habitat hectare of the clearing.	Habitat hectare of offset has to be at least 1.5x the habitat hectare of the clearing.	Habitat hectare of offset has to be at least equivalent to the habitat hectare of the clearing.	
Habitat score constraint	The habitat score of the offset must be at least 90% of the habitat score of the cleared patch.	The habitat score of the offset must be at least 75% of the habitat score of the cleared patch.	The habitat score of the offset must be at least 50% of the habitat score of the cleared patch.	No constraint on habitat score.
Bioregion constraint	Offset has to be from the same bioregion.		Same bioregion if offset is low or medium. Same or adjacent bioregion if offset is high or very high.	
EVC constraint	Offset has to be from the same EVC.	Offset has to be from the same EVC if offset is high significance level or any EVC if very high significance level.	Any EVC.	
Revegetation constraint	The proportion of revegetation is limited to 10% contribution to the habitat hectare.	The proportion of revegetation is limited to 25% contribution to the habitat hectare.	The proportion of revegetation is limited to 50% contribution to the habitat hectare.	No limit on revegetation.
Incentive to upgrade" rule	Where offset is of a higher significance than the clearing, then the amount of the offset will be proportionally reduced (e.g. offsetting losses in medium conservation significance with very high conservation significance gains will reduce the amount of the offsets required by half, i.e. the medium multiplier divided by the very high multiplier: ½ see Table B.)			
Substitution	Upward substitution is possible, i.e. medium significance level clearing can always be offset by high or very high significance lee offset and low significance level clearing can be offset by medium, high and very high offset, etc.			

TABLE 2: TREE OFFSET REQUIREMENTS

CONSTRAINT	TYPE OF CLEARINGS	SIGNIFICANCE LEVEL			
		Very high	*High*	*Medium*	*Low*
Recruitment constraint	Large old trees (LOT) clearings on a remnant patch	8 large old trees per each large old tree cleared	4 large old trees per each large old tree cleared	2 large old trees per each large old tree cleared	No offset requirement.
	Medium old trees (MOT) clearings on a remnant patch	No offset requirement.			
	Large old trees (LOT) clearings as part of scattered trees	8 large old trees per each large old tree cleared	4 large old trees per each large old tree cleared	2 large old trees per each large old tree cleared	10 new recruits.
	Medium old trees (MOT) as part of scattered trees	4 medium old trees per each medium old tree cleared	2 medium old trees per each medium old tree cleared	1 medium old trees per each medium old tree cleared	5 new recruits per each medium old tree cleared
Bioregion constraint	All tree clearings	Offset has to be from the same bioregion.		Same bioregion if offset is low or medium. Same or adjacent bioregion if offset is high or very high.	
EVC constraint	All tree clearings	Offset has to be from the same EVC.	Offset has to be from the same EVC if offset is high significance level or any EVC if offset is very high significance level.	Any EVC.	
Substitution	All tree clearings	Upward substitution is possible, ie. New recruit requirement can be substituted with MOT or LOT. And MOT can be substituted with LOT.			

5. CONTRACT DESIGN

Although BushBroker is colloquially referred to as an electronic market for offsets, it is actually a market for contracts. The contracts commit landowners to the production of a vegetation offset through time. The contract creates an obligation to actively manage vegetation for a period of ten years, followed by the continued permanent protection of a site (DNRE, 2002). There is a temporary decline in the net stock of vegetation when clearing takes place. This shortfall exists until gains on the landowner's site are commensurate with losses from clearing. The environmental integrity of the BushBroker scheme is therefore dependent on whether landowners fulfil their contractual obligations. The Victorian Government is currently working on the design of BushBroker contracts to ensure that they are efficient and environmentally robust.

It is prohibitively expensive to supervise agents, and landholders (agents) hold private information about their degree of compliance with offset contracts. This asymmetric information will introduce the problem of moral hazard, in which landholders have an incentive to shirk their contractual responsibilities. In order to address moral hazard, and in turn to ensure that there is no net loss to the stock of vegetation, the government must design contracts that are incentive compatible. (Laffont and Tirole*,* 1993). Incentive compatible contracts will align the interests of the landholder with the government's objectives by ensuring that it is in the best interest of the landholder to fulfil their obligations to the agreed standard

In order to influence landholders' incentives, the 'strength' of a contract can be varied. There are generally two components of a contract's payment schedule: a fixed wage and the incentive payments that are made for the delivery of outcomes. A 'strong' contract creates strong incentives by making a high percentage of payments conditional on outcomes, while a weak contract is characterised by a highly secure and low or non-existent incentive payments.

If vegetation gains were a deterministic function of landowner's efforts, and if these gains could be perfectly measured, landowners would be paid for their produced outputs (offsets generated). However, the production of an offset is subject to exogenous risks such as climate, bushfire and neighbouring landholders' management practices: these risks are outside of the influence of the contracting parties. In addition to stochastic production, vegetation outcomes are also subject to measurement uncertainty[7]. There is therefore the possibility of a landholder investing effort to generate the targeted vegetation gains, but the measured output not reflecting

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[7] The methodology used to measure outcomes requires specialist training and relies partly on visual inspection of a sight. This not only introduces subjectivity into the measurement process, but also makes it difficult for sellers to gauge the efficacy of their management actions and whether their site is on target for realising expected gains.

their costly investments. If payments are conditional on outcomes, risk averse landholders will need to be paid a premium to accommodate the cost of bearing this uncertainty over payments. An efficient contract will balance the cost of placing risk on the landholder (in the form of a risk premium) against the expected gains of placing risk on the landholder (higher levels of effort invested in the contract).

Bardsley and Burfurd (2008) investigate the design of contracts with respect to incentive structures and the distribution of risk in a vegetation offset market. They find that when landowners are risk averse, the optimal contract makes a percentage of payments for outcomes, with other payments in the form of a wage. In the context of contracts for vegetation offsets, this ‘wage’ takes the form of payments for demonstrated actions that are inputs to the production process. These inputs should be selected to be a deterministic function of the landowner’s effort – for example, the erection of fences and ripping up of rabbit burrows. Bardsley and Burfurd also recommend that to preserve the incentive features of the contract, while minimising the cost of risk premiums, the seller be partly insured against the cost of exogenous events. This can be achieved, for example, by introducing ‘exemption’ clauses so that if particular exogenous events are realised (such as drought), payments are conditioned on input actions rather than outputs.

If the contracts place ‘too much’ risk on landowners (i.e. if contracts are too ‘strong’), then contracts will become inefficiently expensive, leading to sub-optimal level of clearing and development. If contracts are too weak and do not place sufficient risk on landowners, then it will not be in a landholder’s best interests to invest the optimal level of effort in the creation of an offset. This will result in a net decline in the stock of vegetation.

The BushBroker scheme creates an unusual set of circumstances – there are actually three parties involved in the contract. In addition to the ‘buyer’ and ‘seller’, who exist in all market transactions, there is also a third party: the government. The government writes the contracts that are traded in the BushBroker market and becomes the custodian of contracts (the principal) once they have been purchased in the electronic BushBroker market. The government is therefore responsible for monitoring the contracts over a period of time. Monitoring and compliance specifications interact with other features of the contract. As the degree of monitoring is increased, ‘weaker’ contracts can be used to achieve the same level of compliance. Weaker contracts reduce the cost of risk borne by landowners, and are therefore associated with lower prices. To ensure that the government does not distort the market for offsets by subsidising development, buyers must also pay for the monitoring and compliance regime that is associated with the contract they purchase.

The government’s involvement is limited to facilitating and administering transactions, and designing and monitoring contracts. In order for the offset scheme to be efficient, the contract design must optimise the distribution of risk between the buyer and the seller, and buyers must pay for the government's cost of administering a monitoring and compliance regime.

6. DESIGNING A MARKET MECHANISM

Markets form autonomously when there are benefits available to buyers and sellers, and barriers to transactions are minimal. However, efficiently functioning markets do not always evolve due to impediments that are costly to overcome. When government regulation requires transactions to occur, but the emergence of a market suffers from impediments, inefficient trades often take place. In general, an economic system is more efficient if it can provide more goods and services for society without using more resources. In the case of an offset scheme, economic efficiency means that the social value of the economic development (represented by the willingness-to-pay by developers) is maximized and that the cost of finding suitable offsets is minimized (i.e. the lowest cost vegetation offset providers are selected). Market mechanisms are observed to be generally more efficient than other known alternatives.

Where markets are missing or inefficient, the policy objective is to design a market mechanism by overcoming the relevant impediments to transaction. One of the important criteria used to assess the performance of different institutions in overcoming impediments is economic efficiency. In the case of native vegetation offsets, four policy and economic impediments or complexities were identified. Even a single one of these complexities alone has the potential to prevent the emergence of an efficient market. The following is a discussion on the design of the electronic BushBroker exchange, and how research results in mechanism design and experimental economics[8] were considered in order to overcome the complexities mentioned above.

Policy complexities require market participants to understand the regulatory requirements and the 'like-for-like' criteria in order to identify their potential trading partners. Having to understand the details of the rules may prevent some buyers or sellers from participating, increase the transaction cost, or result in outcomes that disadvantage the environment. In the

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[8] Experimental economics evaluates theoretical predictions of economic behaviour by using controlled, scientifically designed tests in the area of game theory, bargaining, auctions, coordination, social preferences, etc. Experiments in auctions focuses on different forms of markets (bilateral negotiations, trading, exchange) and the behaviour of economic agents under different market mechanisms. Mechanism design is the sub-field of microeconomics and game theory that considers how to implement system-wide solutions to problems that involve multiple self-interested agents, each with private information about their preferences. Applications of mechanism design include electronic market design, distributed scheduling problems, combinatorial resource allocation problems.

electronic BushBroker exchange the ‘like-for-like’ constraints discussed above are encoded into the market algorithm. The program automatically verifies whether a match between a clearing and an offset is in accordance with the regulations. Every search and query passes through a ‘verification checkpoint’ to ensure that the legislation is not bypassed. Buyers and sellers only see the segment of the market that is relevant for them. This limits the rich information set available within the market to sell and buy offers that are consequential to the buyers or sellers executing the search. The optimization algorithm that returns the most beneficial option for a particular buyer(s) or seller(s) is constrained by these rules. This ensures that while economic optimization takes place and market participants are seeking their own private interests, they do so within the constraints that the trading rules represent. This ‘smart market’ feature reduces the administrative burden for both market participants and the government.

Transaction complexities/impediments also impose additional requirement that require solution thorugh a market mechanism.

- Information asymmetry: The type of information that market participants hold about the characteristics of the clearings and offsets is a key factor determining the efficiency of the market outcome.[9] The problem of information asymmetry (Akerlof, 1970) was overcome by requiring both buyers and sellers to invest in observable signals by undertaking an assessment process where the quality and quantity of vegetation on the clearing and offset patches are determined. At the electronic BushBroker exchange all information specifying the unit of trade (bioregion, EVC, habitat score, habitat hectare, etc) is observable together with the identity of the market participants leaving no scope for market participants to seek information rent.
- Non-convexities create another impediment. The area of vegetation clearings and offsets are determined by the requisites of the development or the environmental characteristics of the vegetation offset patch. While clearings may have some limited scope to be tailored to reduce the area of environmental damage, the offset come in certain fixed sizes. The size of offsets tends to be much larger than the size of clearings. This ‘lumpy asset’ problem creates difficulties for transactions as buyers may have to pay for the whole even if they only need a small portion of it. Buyers have to bear the risk of buying the large offset in hope of being able to resell the unwanted part later. The ‘lumpy asset’ problem was overcome in the electronic BushBroker exchange by allowing buyers to jointly buy an offset and ‘share’ it among themselves.

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[9] Lynch et al (1986) conducted an oral double auction experimental sessions in which quality could not directly be observed by buyers. The high-quality “supers” yielded a greater surplus over cost than the low-quality “regulars”. Removing the identity of the sellers and providing only post-purchase quality information led to inefficient “lemons” outcomes in which 96% of the units sold were of low-quality (low surplus). The proportion of high-quality (high surplus) units sold increased if sellers’ identities were observable, thereby permitting some building of reputation. The lemons outcome was also observed by Holt and Sherman (1990) in a posted-offer auction with a large number of quality grades.

- Synergies are closely related to non-convexities. Goods are said to be synergistic when the value (or the cost) of a package of goods does not equal to the sum of the values of the individual goods, i.e. the 'whole' can be worth more (or cost less) than sum of the 'parts'. Landowners may have several kinds of vegetations on their land, which they are reluctant to sell separately because of the *economies of scale* to be gained from managing the whole area together. Landowners' marginal costs are likely to decrease with the increase of the area of vegetation managed (e.g. weed control, destroying rabbit burrows, fencing, controlling foxes). On the buyers' side there are *economies of scope*, i.e. developers will place a higher value on purchasing offsets for several clearing patches rather than for individual ones alone as they cannot proceed with the development unless offsets are procured for all clearings. Buyers will be reluctant to buy individual patches due to running a risk of failing to purchase all offsets required for development and hence loosing money. Thus the native vegetation offset market is characterized by the demand and supply of *packages* ('all-or-none') of different type of native vegetation patches. *Combinatorial bidding* (a bidding mechanism that allows participants to express their preferences for single goods as well as for packages of goods) is required to express buyers' and sellers' preferences.

The electronic BushBroker exchange was designed with combinatorial bidding features on both the buyers' and sellers' side. Buyers and sellers can fashion 'all-or-none' offers for a package of items. Buyers and sellers will either buy/sell exactly the package they wanted. If there is no feasible solution to buy/sell the all items in the package no partial execution of a trade will take place (even if partial solutions are available) and the unfulfilled offer will remain in the system. This feature prevents buyers and sellers from the exposure to the possibility of buying/selling part of a package and not being able to buy/sell the rest.[10] While combinatorial

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[10] Combinatorial problems, and economists' explorations thereof, abound but actual successful implementations are rare. For example, in the context of airline slot scheduling, the value of landing slots vary depending on whether the slot to the 'paired-city' is also owned by the airline. Motivated by the airline problem, Grether et al. (1989) modified an existing auction design with an "open book" resale market in which combinatorial bidding contingencies could be informally yet publicly expressed. Also, Rassenti et al. (1982) created a computerized 'smart market' that allowed direct combinatorial bidding with a computerized assignment algorithm. The combinatorial allocation problem also received attention during the design process of the auction of the spectrum rights of the Federal Communication Commission (FCC), see for example Goree and Holt (2005). To tackle the synergy issue, the FCC implemented a 'withdrawal rule' to reduce the potential financial exposure of the bidders. Bidders had the right to withdraw bids on particular licences subject to the obligation to pay the difference between their own and the final winning bid if it was less. "This and other SMR rules led to the results in various FCC auctions that revealed some interesting perverse strategies. In particular, individuals would withdraw and then bid just below their withdrawn bid to signal a willingness to not compete. To manage eligibility, bidders would bid on items for which they did not have value to maintain activity without showing their hand on what they were interested in bidding for (this was called "parking"). These perverse strategies incentives prompted rule changes and in later implementations restricted the number of withdrawals allowed in order to reduce this features for "gaming" purpose rather than to eliminate financial risk." (p.11154, Porter et al, 2003) One example of a successful implementation of a combinatorial auction was the sale of aquaculture sites in the Port Phillip Bay in Victoria, where the combinatorial auction program designed by Prof Charles R. Plott at Caltech was used. The features of a very early version of this auction was produced at as an application of the electronic spectrum for the FCC. See Plott (2000).

auctions have a potential to dramatically increase efficiency, their implementation raises a set of computational[11] and strategic questions that need to be resolved.

Strategic complexity refers to the natural tendency of buyers and sellers to act strategically when facing competition or having an opportunity to free ride on others buyers' and sellers' effort (e.g. hold out and expect other market participants to increase/decrease their buy/sell offers). Such strategic posturing has the potential to reduce efficiency or to lead to the complete lack of trading activity. In order to overcome this complexity, the market mechanism has to bring the natural market competitive forces to competitive pressures. Even small variations in the market institution can have large effects on both the relevant game-theoretic predictions and on the behaviour of subjects. A series of strategic tools are part of the design of the electronic BushBroker exchange.

- Symmetry in market design: In order to accelerate the convergence of buy and sell offers, competitive forces are created on both side of the market. A market institution that distinguishes the available strategic tools for buyers and sellers has the potential to influence offer prices. As the purpose of the native vegetation offset scheme is to allow conservation values to compete on equal grounds with economic development, it is important that the market design implemented by the government (a third party ensuring equity and fairness in the transactions) does not favour either one or the other side of the market. The electronic BushBroker exchange is symmetric in the sense that *both* buyers and sellers are required to post binding offers and *both* can deviate from the posted prices. *All* market participants can access *all* the information available to any of the buyers or sellers at any time. This feature ensures that the institution does not limit the flexibility of market participants or create bias for either the buyers or the sellers by providing information to them that the other side does not have.[12]
- Multiple binding offers: The price discovery process at the electronic BushBroker exchange has to overcome a coordination problem. Prices are discovered through the continuous interaction of buyers and sellers. Both buyers and sellers can revise their offers, and can also tailor their packages to 'fit' a desirable multilateral trade. 'Cheap talk' (non-binding

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[11] For example, at any point in time when the system is interrogated, there is no guarantee that the solution (the selection of the winning bids and asks) will be unique and/or that when the number of participants, packages, offers and items increases, the solution can be found in a "reasonable" amount of time. There is a set of conventions and mathematical solution (e.g. partitioning searches) that can help resolve some of these issues but even so this is an area which has so far been largely unexplored.

[12] Market institutions have the potential to influence the market price and reduce economic efficiency. For example, a posted offer market with the requirement for sellers to post prices will raise prices and reduce market efficiency. For example Plott and Smith (1978) compare different trading institutions and reveal the inefficiencies that can result from a rule that limits the ability of traders to deviate from posted prices. If prices are distorted by the market design it is not only a question of equity or fairness but also that this could also result in inefficient transactions over a long period of time. Price distortions take time to correct in a marketplace because new market participants look at historical prices to guide them when formulating offers and thus their offers keep reinforcing the distortion.

offers) is not allowed as such feature would hinder or even prevent the price discovery.[13] Instead, an unlimited number of *revisions* of binding offers are allowed. Typically, at double auctions there is an 'improvement rule' which requires that buy/sell offers to be successively higher/lower. At the BushBroker exchange there is no improvement requirement. Each vegetation patch may have several binding buy offers (for clearings) and several binding sell offers (for offsets) active in the system at any point in time. Furthermore, vegetation patch(es) may be included in several different package offers of which only one may become a winner. (If there are package offers that contain one or more of the same item(s), these package offers are treated as 'either-or' by the system as not more than one can become a winner due to the overlaps among the items that these package offers contain.) The 'rank queue' feature automatically selects the best buy offer and the best sell offer when looking for the trade that maximizes efficiency. This feature further enhances the efficiency of the market and it is also consistent with the combinatorial auctions where previous non-winning bids may become provisional winners at some later stage in the market.

- Strategic information provisioning: The success of a continuous double auction largely depends on the information that is provided to the participants regarding their position relative to competition. Providing answers to questions such as "how much shall I offer to be winning?", "who are my potential trading partners?", "who is looking at my offers?' "what would it take for the competition to displace me?" are important in order to facilitate the bargaining process and to naturally "push" market participants by competitive forces. The electronic BushBroker exchange provides a complete transparency of both buy and sell offers to all participants. All clearing and offset patches and packages and all offers can be seen by all participants at any time. The program allows a 'watch list' to be created in order to help tracking relevant offers. A range of search and query functions is available for both buyers and sellers to help optimize their positions. For example, buyers can run a simple search to find potential sellers with whom a bilateral trade is feasible, or vice-versa. A buyer or seller can also run *a* more complex search to find buyer(s) *and* seller(s) with whom a multilateral trade is feasible. The simple search only scans the opposite side of the market to returns potential trading partners. A more complex search scans both sides of the market, evaluating all combinations of buy and sell offers, and listing all potential multilateral trades. (While running either the simple or the more complex

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[13] Some electronic exchanges facilitate a price discovery process by allowing non-binding offers to be placed into the system during the pre-opening period (also referred to as "sunshine trading") or place offer that can be modified or withdrawn prior the market being called. This way market participants send non-binding signals to the market about their price expectations prior to transactions taking place. While this may be beneficial to overcome difficulties with information gaps during overnight closure of an exchange, these solutions are not suited for the combinatorial double auction as they prolong price discovery without adding any information.

search, the verification of the trading rules has been taken care of by the *'smart market' feature* discussed above under *policy complexities*.)

- Fashioning trades: There are additional functions to help buyers and sellers position themselves so to enhance competition on both sides of the market. By using the advanced search function, buyers and sellers have the opportunity to fashion a trade to suit their preferences. Buyers and sellers can exclude their competitors or any other parties from a multilateral trade or they can include others in the trade. Combinatorial auctions enhance efficiency by allowing small buyers (sellers) to displace large buyers (sellers) if they are jointly willing to pay more (ask less) than the large buyer (seller). However, there is a strategic incentive for both buyers (sellers) to free-ride on the effort of the other buyer (seller) which may prevent this coordination. The "threat" of being excluded from a trade overcomes the natural tendency to hold out and to free ride.
- Market making: 'Market makers' are market participants who have the incentives to find and the right to execute trading opportunities among buyers and sellers. Market makers fulfil an important role by facilitating transaction at thin, slow, complex markets. A novel solution at the BushBroker exchange rewards all market participants for becoming market makers, i.e. the buyer or the seller who finds a trade or brings a trade together is able to capture any financial and "vegetation surplus" that is a result of that trade.

Time complexities must also be considered in the market design. Buyers and sellers arrive to the market asynchronously. Also, both buyers and sellers have time preferences, i.e. they attribute value to knowing whether offsets can be sold or clearings can be offset within a certain period of time. The natural condition of the native vegetation varies with exogenous environmental variables and, therefore, there is a time limit how long the habitat score assessment is valid for. (If the vegetation offset is not sold within this period of time, a new assessment is required to update the quality of the native vegetation offset that may have changed over time.) Similarly, developers wish to know within a certain period of time with certainty whether offsets can be obtained for the clearings they propose and if so at what cost. In mature, well established markets for large volume of homogenous goods (e.g. commodity markets, financial markets) futures trading has evolved to address time preferences. Due to the highly heterogeneous nature of the items traded at the electronic BushBroker exchange and the trading rules that form a "layer" between clearings and offset and therefore making it difficult to estimate future demand and supply, we were unable to address in depth the time complexities in the electronic BushBroker exchange. Market participants maintain all the control over the modification, execution or cancellation of any offers in the system, allowing them to update these offers if their preferences change.

In summary, the market design has to overcome the complexities described above and also it has to work efficiently. The following section describes the experimental tests and the simulation results that evaluate the performance of the electronic BushBroker exchange under various scenarios.

7. TESTING THE MARKET MECHANISM AND EVALUATING ALTERNATIVE MARKET INSTITUTIONS

7.1 EXPERIMENTAL TESTS AND EVALUATION

The electronic BushBroker exchange has been the subject of a series of experimental tests. Initial experiments were geared towards evaluating the software performance and usability and later experiments towards assessing efficiency and to elucidate specific bidding behaviour. Further experiments focused on solving the double sided combinatorial problem using increasingly complex parameter sets.

During the experimental tests we were looking for answers to two key questions: “does the designed institution achieve efficiency?”, and if so, “does it achieve efficiency for understandable reasons?” If the experimental tests confirm that the market achieves an efficient outcome and the test results provide us with information how and why it does so, then we can proceed with gradually scaling up the data by increasing the complexity of the parameter set and the number of buyers and sellers and eventually reaching the complexity of the “real market”.

Sessions ran normally for three hours and the number of subjects varied between 6 to 8 people in each session. Several versions of the electronic BushBroker exchange were programmed, each building on the previous version by incorporating further extensions to the rules, or other market features. The results of the experiments have overwhelmingly endorsed the electronic market as a simple and effective solution to the complex environment of native vegetation trading.

Some more specific results include:

- <u>Comprehension of overall market design:</u> a double sided combinatorial market with smart features could be quite challenging for users. Due to its novel feature, a series of experiments focused on finding the best way to communicate its use to the users. User manuals were made and distributed to the experimental subjects who, over several rounds of experiments, gave valuable feedback and helped refined the user manual. Initial rounds limited the search functions to single sided search (buyers were able to search sellers and vica-versa) and once subjects understood these functions well double-sided search was introduced.

- Testing the 'smart market' features: The 'smart' feature of the market would make the rules invisible to the subjects and would allow them to execute transactions without being aware of the regulatory requirements. We deliberately did not explain any of the rules to the subjects. During the instructions we explained that there were certain trading rules that had been programmed into the market and that these trading rules guide who the subjects could trade with. Most subjects were oblivious to these trading rules and did not ask any questions.[14]
- Complexity of parameter sets: Another set of experiments tested increasingly complex parameter sets. The inherent complexity in the native vegetation trading rules made the construction of appropriate experimental parameter sets challenging. The general strategy we took was to introduce participants to the program with a series of simple parameter sets then develop the complexity of the parameter sets with the expectation of increasing complexity in the trades. Complexity was increased in several ways, for example by increasing the number of patches, increasing the diversity of patch characteristics, introducing trees and by introducing overlapping markets.
- Efficiency: The efficiency rates observed in the experimental sessions were generally quite good. We observed 50% and 25% of experimental rounds achieving 100% efficiency over two sessions. The incidence of inefficiencies tended to increase with the complexity of the parameter sets. As we evaluated the efficiency at the end of each period, one possibility is that what we observe as inefficiencies could have been efficient given the vegetation patches in the system at the time of execution. The circumstantial evidence indicates that this scenario was responsible for at least some of the less efficient outcomes. Further examination revealed that in the periods with less than 100% efficiency the trades occurred mostly at the very beginning, or the very end of the period. This indicates that inefficient outcome was partly due to participants being able to trade their patches before others entered the market with better deals or that the there was an 'end of period effect' at play whereby participants are more willing or more anxious to trade as the period deadline looms large. Those patches that contained a high number of components (i.e. LOT, MOT, habitat hectare) were more likely to be not traded than their smaller counterparts even if they were part of the efficient outcome. At this stage we do not have a theory of dynamics to help us understand the reasons for or implications of such patterns
- Bidding behaviour: The data and theory are insufficient to construct a robust econometric analysis to reveal individual bidding behaviours; therefore we only intend to note some observed

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[14] The only time when some subjects had questions relating to the rules was when trees were introduced into the complexity. Subjects were advised that the program only lists offers that are in accordance with the regulations. Participants accepted this explanation and remained unaware of the details of the trading rules.

behaviour during the experimental test.[15] The most common bidding heuristic was following the 'gradient search method'.[16] In our case, at each point in time for each buyer and seller the gradient (the steepest slope) points to the highest profit obtainable. The magnitude of the gradient determines "how fast" the profit rises and the direction shows the "fastest way" to obtaining that profit. Every buyer and seller makes incremental improvements in their positions. The gradient search method tends to converge on local optimums. The use of this heuristic is motivated by the fact that many optimization problems are too difficult for market participants to calculate so they tend to revert to some rational yet simple procedure in solving the complex problem they are confronted with. The "game" is perceived by the bidders not in its entirety but as a "sequence of opportunities" where bidders are making local improvements without consideration of global strategies. The use of the 'gradient search' heuristic is made easy to the bidders by allowing all market participants to interrogate the system at any point in time to find the solution that leads to the highest surplus. If this surplus is positive market participants usually immediately execute such trades. The availability of the function of 'market making' for everyone seems to successfully place a "displacement pressure" on all bidders and hence we observe active and efficient participation.

7.2 SIMULATION RESULTS

There are several ways that clearing and offset patches are traded, or could be traded. Four simulation treatments, representing two market institutions, and two measures were employed to assess the efficiency of matching clearing and offset patches. The purpose of the simulations was to test the robustness of the proposed institutions by comparing the efficiency outcomes and assessing whether and how the market institutions overcome the policy and economic complexities discussed above and how the measures employed compare in terms of economic efficiency.

Simulation data – The Victorian government maintains a register that lists over 900 vegetation offset patches (belonging to approximately 260 sellers) and over 200 vegetation clearing patches (belonging to approximately 40 buyers). One bioregion (Goldfileds – bioregion 8) was selected to populate the market for the purpose of simulation. The Goldfields bioregion is a fairly "active" bioregion north west of Melbourne (See Figure1) where clearing and offset patches

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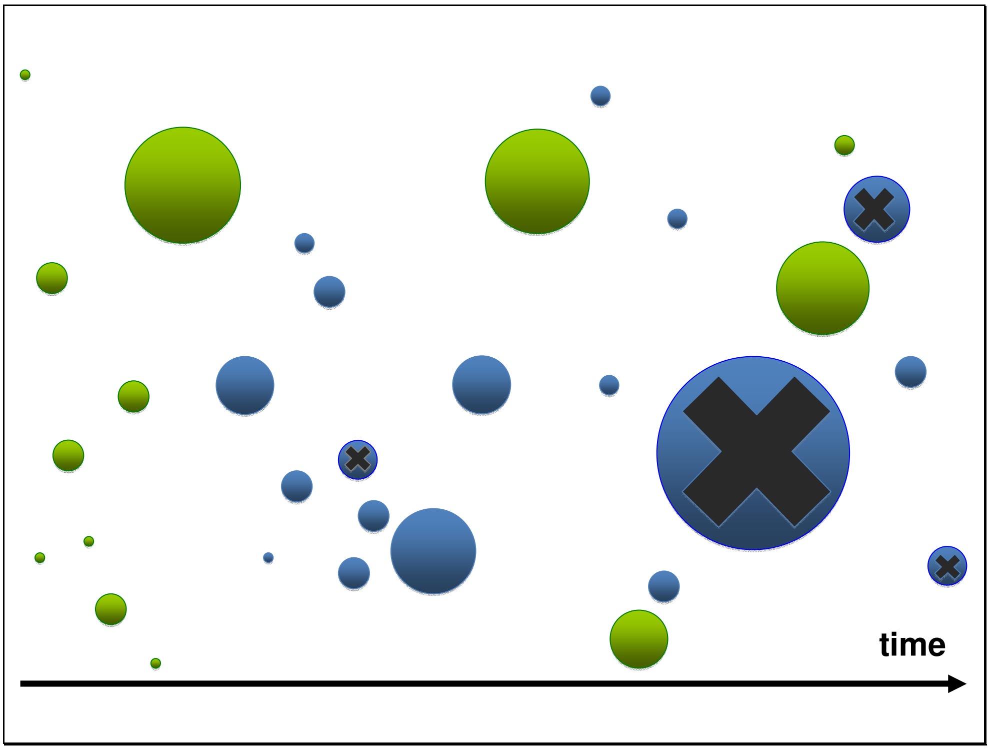
[15] The current version of BushBroker does not have the capacity to record time stamped user price revisions, though this function is presently being built into the system. The specific patch price movements over the course of the experiments are unknown, but these will be available for future experiments, which will allow a more thorough investigation of bidding strategies.

have been evaluated and verified in terms of the vegetation significance, type, quality, area etc. If a buyer or a seller had multiple clearing or offset patches, these were packaged together for each buyer and seller. Artificial prices were generated for the packages representing the maximum buy offers (or maximum willingness-to-pay) for clearings and minimum sell offers (or minimum willingness-to-accept) for offsets. As the Contact IDs listed in the register are generated sequentially, it was possible to reconstruct the order of arrival of the buy and sell requests. Figure 2 (below) is a visual representation of the clearing (blue) and offset (green) patches and packages. The "size" of the offer (in terms of maximum buy offer and minimum sell offer) is represented by the *size* of the blue and green circles. The sequence of the buy and sell requests is denoted by the *position* of the blue and green circles along the x-axis representing time.

FIGURE 2. CLEARING (BLUE) AND OFFSET (GREEN) PATCHES AND PACKAGES IN BIOREGION 8.



Feasibility test – Search routines were employed to determine whether the clearing patches in the data set had a feasible match from among all the selected offsets in bioregion 8. Four of the clearing packages did not have a feasible match. These are marked with a dark grey cross in

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[16] The 'gradient search method' is one of the most popular non-linear optimisation techniques. Other, for example nature-inspired heuristics (ant colonies and particle swarm intelligence) are also sometimes used in finance and applied econometrics as many optimisation problems cannot be dealt with adequately using classical tools.

Figure 2. There are several reasons that explain why a feasible offset might not be found. Offsets may not satisfy: the habitat score constraint (habitat score of offsets are not high enough); the habitat hectare constraint (available habitat hectare is not enough); or the recruitment constraint (the number of trees available is not enough). In the case of the largest clearing package (represented by the largest blue circle in Figure 2); 14 of the 15 patches that are part of that package can be matched with offsets and only one of the clearing patches cannot. If package bidding were not available this buyer would be exposed to the possibility of buying suitable offsets for 14 of the clearing patches and still missing offsets for one remaining clearing patch. As the benefit of buying the offsets is only realized when all the clearings are offset (and hence development can take place), the absence of package bidding could result in financial loss for the buyers if they make financial commitments without the security of being able to offset all the clearings. In order to simplify the graphs, the non-feasible clearing packages are excluded from consecutive representations.

Simulation procedures and treatments – While one of the reasons to use experimental techniques is to test the efficient outcome in the presence of strategic incentives for a given market institution, simulation techniques allow us to make a different kind of comparison. Simulation techniques assume that a) there are no strategic complexities and b) that all market participants truthfully reveal their values and costs. For these reasons simulations allow us to compare the best possible outcomes of these market institutions.

Comparison of market institutions – First, we simulated two market institutions where buy and sell offers arrived over time.

- <u>Bilateral negotiations</u> - The first institution simulated the finding of suitable offsets with bilateral negotiations. This simulation models the current practice where every time a request is received by a buyer, a list of offsets that satisfy the requirements is generated and is given to the buyer. The list includes the specifications (location, area, habitat score, type, etc.) of the vegetation offsets and the contact information of the sellers. The buyer then negotiates with one or more of the sellers. Figure 3A shows the five transactions as a result of running the simulation of bilateral negotiations. In every transaction (except one) there is a single buyer and a single seller. This treatment picks up some of the lowest willingness-to-pay and correspondingly the lowest willingness-to-accept buyers and sellers generating $54,950 in surplus. In the analysis that follows the total surplus (the sum of consumer and producer surplus) is used for comparison.[17] One of the buyers is only required to offset some trees. As trees are sold only in

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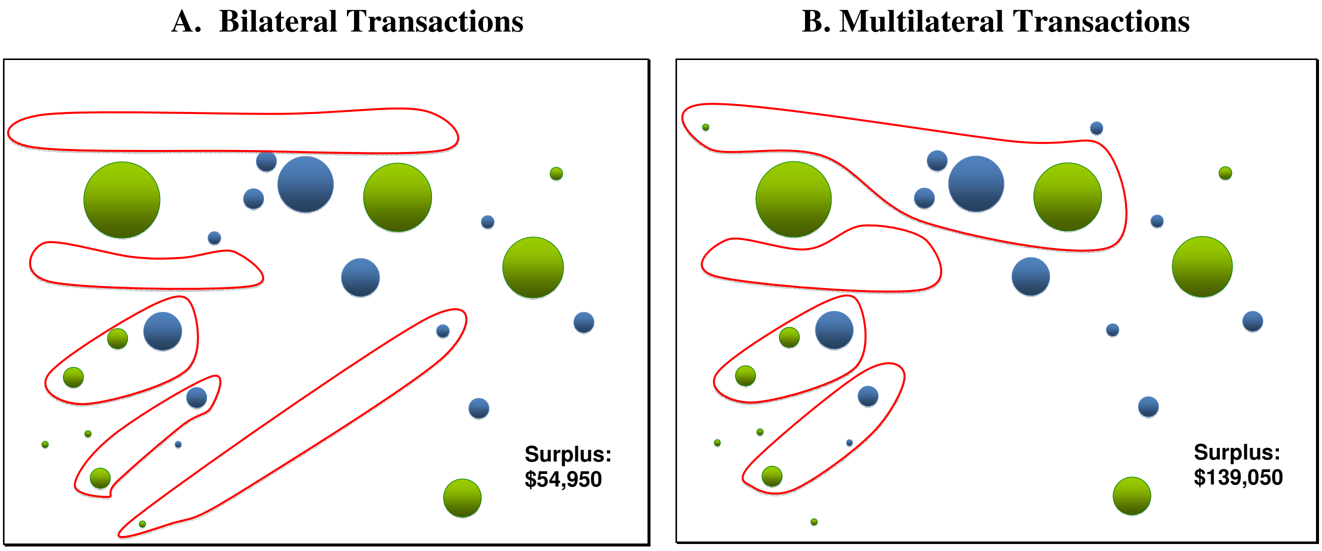
[17] This surplus can be interpreted as the wealth created by the trades as it represents "how much better off" the parties are as a result of these transactions. Surplus is measured by the difference between the sum of maximum willingness-to-pay and the sum of minimum willingness-to-accept of the buyers and sellers who are involved in the trade.

packages jointly with habitat hectare (HH), this buyer ends up buying 7.62 HH vegetation which he/she does not need. Due to the nature of negotiations in this treatment, the buyer is not able to share the purchase with any of the other buyers even if another buyer would be willing to contribute to the trade.

- Multilateral negotiations – The second simulation models multilateral negotiations where either the buyer or the seller can make transactions with any of the buyer(s) and seller(s) whose offers were received prior to his/her request. Similar to the bilateral treatment, trades take place sequentially. Under this treatment, four transactions take place (see Figure 3B). The first two transactions are the same as under the previous simulation. In one of the transactions, two buyers are able to jointly buy the package that previously one of the buyers had to purchase. It is interesting to note that in one of the transactions (shown at the upper part of Figure 3B) a small offset is needed to make a transaction possible between three buyers and a large seller. This signifies the importance that some small patches may have in contributing to transaction between several buyers and sellers. In general, the value of clearings and offset packages are greater in this treatment that in the previous one and the total surplus generated by the transaction increased to $139,050.

FIGURE 3. VISUAL REPRESENTATION OF THE RESULTS OF THE TWO MARKET INSTITUTIONS


A. Bilateral Transactions

B. Multilateral Transactions

Table 3 shows that the multilateral transactions outperformed the bilateral transactions treatment. In the bilateral transactions the surplus was $54,950 while in the multilateral treatment the surplus was $139.050, representing an increment of 153%.

TABLE 3. COMPARISON OF SURPLUS ACHIEVED UNDER DIFFERENT MARKET INSTITUTIONS.

	Surplus achieved
Bilateral transactions	54,950
Multilateral transactions	139,050

When we compare the bilateral and multilateral treatments based on the surplus achieved relative to the maximum surplus achievable at the time of trade the difference is more striking. Table 4 shows that *ex post* efficiency of the multilateral transactions were in fact contemporaneously 100% efficient at all times. The contemporaneous efficiency of the bilateral transactions were initially 100% but as the number of offers increased the efficiency decrease to 60%, then to 14% and even down to 5%.

TABLE 4. COMPARISON OF CONTEMPORANEOUS EFFICIENCY OF THE BILATERAL AND MULTILATERAL TRANSACTIONS.

	Bilateral transactions			**Multilateral transactions**		
	Surplus from trades	**Maximum surplus achievable at the time of trade**	**% of maximum achieved**	**Surplus from trades**	**Maximum surplus achievable at the time of trade**	**% of maximum achieved**
Trade 1	4,850	4,850	**100%**	4,850	4,850	**100%**
Trade 2	20,000	33,100	**60%**	33,100	33,100	**100%**
Trade 3	5,000	36,300	**14%**	23,200	23,200	**100%**
Trade 4	6,700	135,400	**5%**	77,900	77,900	**100%**
Trade 5	18,400	128,900	**14%**			
Total surplus	**54,950**			**139,050**		

Most bilateral trades only involve a single buyer and a single seller, relative to the multilateral treatment where trades involve up to 5 participants. The restriction for buyers to purchase the necessary offset packages alone rather than jointly with other buyers erodes efficiency. The simulation above shows that different market mechanisms applied for solving the same problem can result in significantly different outcomes.

Comparison of measures – Second, we used two measures to compare economic efficiency. Besides assuming no strategic complexities and that market participants truthfully reveal their values and costs, these measures also assume that buy and sell offers are coordinated and are all available at one point in time.

- <u>Time coordinated rule of thumb measure</u> – The "time coordinated rule of thumb" measure represents a natural tendency of solving this complex problem. When people are confronted with solving these complex problems, a very reasonable approach is to aggregate the required habitat hectare and the number of trees in the same EVC. People tend to then take the characteristics of the clearing with the most stringent matching requirements and try to find a seller who complies with the trading rules and is “big enough” to satisfy this aggregate demand. Usually the largest seller is considered first. If the largest seller is not enough to satisfy the clearings then either more sellers are added or some of the buyers are taken out.[18] Figure 4A shows an elegant solution using this method. Most of the clearing patches can be satisfied by a single offset package resulting in total surplus of $79,400.

- Time coordinated optimized measure – Another measure we simulated is a “time coordinated optimized” measure. Similar to time coordinated rule of thumb this measure also aggregates the buy and sell offers over time. This measure compiles *all the combinations of all the clearings* and *all the combinations of all the offsets* and finds (if it exists) the pair of feasible clearing and offset combinations that generates the highest surplus (while it satisfies the offset rule requirements). Figure 4B shows that using this method gives preference to small buyers if jointly they are willing to pay more for the offsets than their larger counterparts. Also this method will give preference to low cost sellers if they are jointly willing to sell for less than their larger counterparts.

FIGURE 4. VISUAL REPRESENTATION OF THE RESULTS OF THE TWO SIMULATED MEASURES

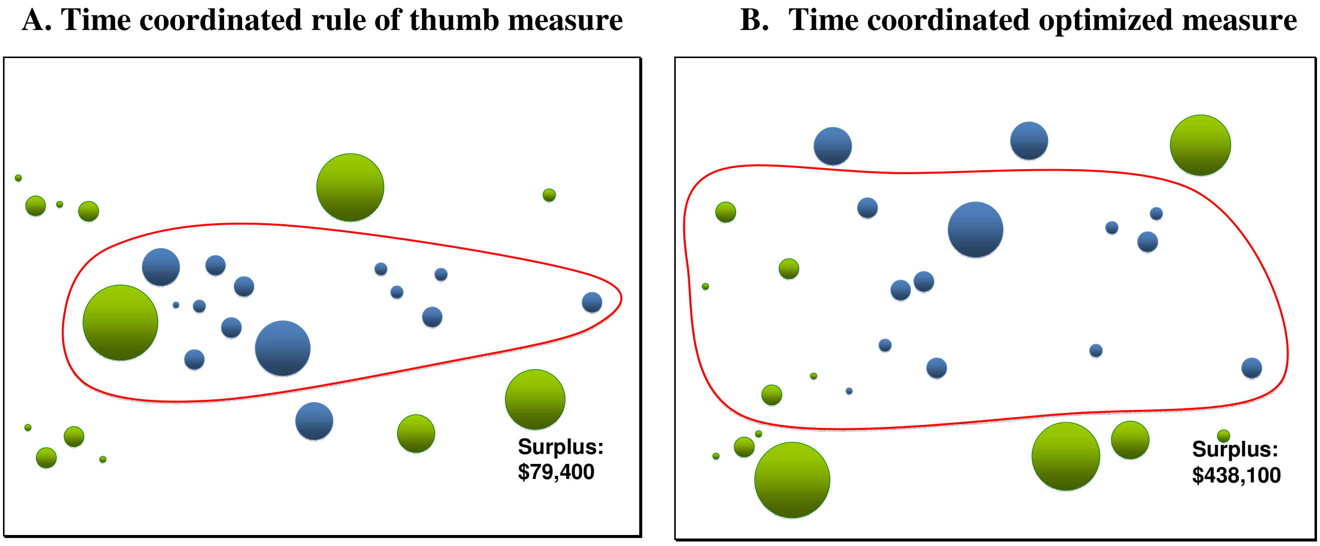


Table 5 shows that the time coordinated optimized measure achieved a much higher efficiency than the time coordinated rule of thumb measure. The maximum surplus achievable is $438,100. The time coordinated rule of thumb measure only achieves $79,400 surplus, which is

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[18] One example of using this treatment was offsetting the vegetation clearings for the construction of the Geelong Bypass. Buyers were project managers from VicRoads, each of whom was responsible for the development of a section of the bypass and had a separate package of clearings. The Department of Sustainability and Environment (DSE) ran a procurement auction and collected bids from landowners. The vegetation offsets with the

only 18.12% of the total surplus. Using the time coordinated rule of thumb measure usually requires that when patches are aggregated, the highest significance level and the highest significance score are applied across all the clearing patches. This can result in the exclusion of some offset patches that may otherwise match with some part of the aggregated package. Also, the time coordinated rule of thumb measure does not attribute importance to the values and costs of packages. Its primary focus is to aggregate the clearing patches (irrespective of the values) and try to find the minimum number of offset packages (irrespective of the costs). The time coordinated optimized measure picks the pair of offset and clearing packages that generate the highest surplus irrespective of the number of offsets and clearings involved in the trade.

TABLE 5. COMPARISON OF SURPLUS ACHIEVED UNDER THE TWO MEASURES.

	Surplus achieved	**% of total surplus**
Time coordinated rule of thumb measure	79,400	18.12%
Time coordinated optimized measure	438,100	100.00%

Based on the experimental and simulation results, continuous double auction with multilateral trade executions is recommended to solve the policy and economic complexities in the native vegetation offsets market with an efficient outcome.

8. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, when comparing different market institutions, subtle differences in the institutional rules may result in large differences in efficiency, while also effecting how and to what extent these institutions overcome the economic and policy complexities. Prior to the design taking place, diagnosing all economic and policy complexities is important. Also, there may be trade-offs between overall efficiency and other considerations.

Prior to testing of the electronic BushBroker exchange, we wanted to answer two key questions: “does the designed institution achieve efficiency?” and if so “does it achieve efficiency for understandable reasons?” If the experimental tests confirm that the market achieves an efficient outcome and the test results provide us with information how and why it does so, then we can proceed with gradually scaling up the volume and complexity of the data till we eventually reach the level of complexity of the “real world”.

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corresponding bids were presented to the buyers who ended up aggregating their clearings and jointly purchasing two of the offset packages.

The proposed institution of continuous double auction with multilateral trade executions overcomes the economic and policy complexities present in the native vegetation offset market. Laboratory test results show that the electronic BushBroker exchange achieves very high efficiency levels. Simulations also show that using multilateral transactions we can achieve much higher efficiency levels than by using bilateral transactions. We are also able to understand the reasons of the high efficiency levels. Individual bidding behaviour during the experimental tests revealed that the market participants follow the 'gradient search method', i.e. buyers and sellers make incremental improvements in their positions. Market participants perceive the market as a "sequence of opportunities" where bidders are making local improvements without consideration of global strategies. We observe active and efficient participation.

Experimental and simulation test results provide us with enough understanding and confirmation that we can proceed with scaling the experimental tests, i.e. we can increase the complexity of the data set and the increase the number of buyers and sellers so that eventually we end up with the "real" market. We will also move toward a temporal experimental setting where experimental periods will last for several weeks and clearing and offset patches will arrive asynchronously. This setting allows us to test the market with a more realistic information provisioning.

Without a thoughtful design, it is unlikely that an efficient market would naturally emerge. Any one of the complexities described above has been known to prevent transactions to occur or to result in inefficient trades. To the best of our knowledge, no market institution that efficiently overcomes the cumulative complexities inherent in the native vegetation offsets market has been designed or implemented.

Offset schemes have the potential to allow valuable economic activity to take place without decreasing the net stock of biodiversity. Environmental markets are, however, different from ordinary commodity markets. Combinatorial problems, trading rules, timing issues, etc, often make it difficult for transactions to take place. Government intervention may be required to determine the metrics, define trading rules, and design contracts and a market mechanism that facilitates beneficial transactions for both buyers and sellers while maintaining the environmental stock over time. Besides leading to important economic and environmental benefits, these elements of an offset scheme jointly result in reduced time

- to find approved assessors of native vegetation,
- to study and understand the 'like-for-like' rules,
- to find a matching buyer/seller,
- to negotiate a price,

- to administer and monitor contracts due to their standardised nature, and
- to sell/buy residual assets.

In summary, successful implementation of the electronic BushBroker exchange will enable efficient trade-offs to take place between economic development and environmental conservation. The price to be paid for vegetation loss and for vegetation offsets will be jointly determined and also in relation to other economic activities (such as housing development or grazing). This will be an important step in allowing environmental conservation to compete on equal grounds with economic interests.

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APPENDIX. TRANSACTIONS FROM THE FOUR SIMULATION TREATMENTS

The Contact ID and Patch number of the buyers and sellers have been changed in order to protect their identity.

A. Bilateral transactions

Contact ID	Price	Patch#	HH	Bio	EVC	Sig	Score	Area	LOT	MOT
10	120000	19453	0	8	61	M	0	0	31	0
7	64000	19413	0.06	8	72	H	0.39	0.23	9	0
		19415	0.66	8	72	H	0.24	3.93	36	5
		19417	1.16	8	72	0	1	10.53	2	0
4	51150	19389	0.048	8	61	L	0.22	0.39	1	0
		19391	0.024	8	61	L	0.16	0.19	2	0
		19393	0.25	8	61	M	0.46	1.55	18	0
		19395	0.39	8	61	0	1	3.53	0	0
		19397	0.77	8	67	0	1	7.03	0	0
		19399	0.81	8	175	0	1	7.39	1	0
		19401	1.22	8	61	0	1	11.11	0	0
		19403	2.23	8	61	0	1	20.28	0	0
12	64500	19457	3.36	8	20	M	0.6	5.6	0	0
6	44500	19407	0.199	8	22	M	0.49	0.92	2	5
		19409	0.867	8	20	M	0.63	3	2	5
		19411	2.753	8	61	M	0.59	10.01	6	5
14	65000	19461	0	8	61	L	0	0	8	20
3	60000	19383	1	8	67	H	0.48	3.68	1	5
		19385	0.832	8	67	VH	0.55	2.9	2	5
		19387	0.345	8	68	VH	0.61	1.14	22	5
21	26200	19499	0	8	61	L	0	0	1	5
1	19500	19371	0.108	8	67	H	0.42	0.62	0	5
		19373	0.429	8	67	0	1	4.04	0	0
		19375	0.088	8	68	VH	0.43	0.45	5	5
22	31700	19501	0.715	8	20	L	0.55	1.3	1	0
		19503	0.084	8	61	M	0.42	0.2	0	0
		19505	0.06	8	20	M	0.6	0.1	1	0
8	13300	19419	0.7	8	61	H	0.64	3.39	2	0
		19421	0.1	8	61	M	0.56	0.69	0	0
		19423	0.1	8	61	M	0.55	0.37	1	0
		19425	0.8	8	61	M	0.54	5.21	0	0

B. Multilateral transactions

Contact ID	Price	Patch#	HH	Bio	EVC	Sig	Score	Area	LOT	MOT
10	120000	19972	0	8	61	M	0	0	31	0
4	51150	19908	0.048	8	61	L	0.22	0.39	1	0
		19910	0.024	8	61	L	0.16	0.19	2	0
		19912	0.25	8	61	M	0.46	1.55	18	0
		19914	0.39	8	61	0	1	3.53	0	0
		19916	0.77	8	67	0	1	7.03	0	0
		19918	0.81	8	175	0	1	7.39	1	0
		19920	1.22	8	61	0	1	11.11	0	0
		19922	2.23	8	61	0	1	20.28	0	0
7	64000	19932	0.06	8	72	H	0.39	0.23	9	0
		19934	0.66	8	72	H	0.24	3.93	36	5
		19936	1.16	8	72	0	1	10.53	2	0
12	64500	19976	3.36	8	20	M	0.6	5.6	0	0
11	13100	19974	0.29	8	61	L	0.29	1	0	0
6	44500	19926	0.199	8	22	M	0.49	0.92	2	5
		19928	0.867	8	20	M	0.63	3	2	5
		19930	2.753	8	61	M	0.59	10.01	6	5
14	65000	19980	0	8	61	L	0	0	8	20
13	31500	19978	0.5712	8	61	M	0.48	1.19	3	0
8	13300	19938	0.7	8	61	H	0.64	3.39	2	0
		19940	0.1	8	61	M	0.56	0.69	0	0
		19942	0.1	8	61	M	0.55	0.37	1	0
		19944	0.8	8	61	M	0.54	5.21	0	0
3	60000	19902	1	8	67	H	0.48	3.68	1	5
		19904	0.832	8	67	VH	0.55	2.9	2	5
		19906	0.345	8	68	VH	0.61	1.14	22	5
15	60000	19982	3.84	8	61	M	0.48	8	4	0
18	145000	19990	0.0224	8	61	L	0.28	0.08	0	0
		19992	0.0756	8	61	L	0.28	0.27	0	0
		19994	0.0102	8	61	M	0.34	0.03	0	0
		19996	0.007	8	61	M	0.35	0.02	0	0
		19998	0.012	8	61	M	0.3	0.04	0	0
		20000	0.0364	8	61	M	0.52	0.07	0	0
		20002	0.0273	8	61	M	0.39	0.07	0	0
		20004	0	8	61	M	0	0	7	5
17	75000	19986	0	8	175	M	0	0	5	5
		19988	0	8	803	M	0	0	5	5
20	182600	20010	0.09	8	61	M	0.5	0.42	2	0
		20012	0.22	8	61	M	0.47	1.07	2	0
		20014	0.15	8	61	M	0.46	0.75	4	0
		20016	1.59	8	175	VH	0.58	5.15	34	20
1	19500	19890	0.108	8	67	H	0.42	0.62	0	5
		19892	0.429	8	67	0	1	4.04	0	0
		19894	0.088	8	68	VH	0.43	0.45	5	5

C. Time coordinated rule of thumb

Contact ID	Price	Patch#	HH	Bio	EVC	Sig	Score	Area	LOT	MOT
10	120000	20299	0	8	61	M	0	0	31	0
17	75000	20313	0	8	175	M	0	0	5	5
		20315	0	8	803	M	0	0	5	5
14	65000	20307	0	8	61	L	0	0	8	20
21	26200	20345	0	8	61	L	0	0	1	5
18	145000	20317	0.0224	8	61	L	0.28	0.08	0	0
		20319	0.0756	8	61	L	0.28	0.27	0	0
		20321	0.0102	8	61	M	0.34	0.03	0	0
		20323	0.007	8	61	M	0.35	0.02	0	0
		20325	0.012	8	61	M	0.3	0.04	0	0
		20327	0.0364	8	61	M	0.52	0.07	0	0
		20329	0.0273	8	61	M	0.39	0.07	0	0
		20331	0	8	61	M	0	0	7	5
25	26300	20369	0.0384	8	61	M	0.48	0.08	4	0
13	31500	20305	0.5712	8	61	M	0.48	1.19	3	0
30	54600	20411	1	8	175	M	1	1	0	0
24	46500	20361	0.715	8	20	L	0.55	1.3	1	0
		20363	0	8	61	L	0	0	6	5
		20365	0.084	8	61	M	0.42	0.2	0	0
		20367	0.06	8	20	M	0.6	0.1	1	5
11	13100	20301	0.29	8	61	L	0.29	1	0	0
22	31700	20347	0.715	8	20	L	0.55	1.3	1	0
		20349	0.084	8	61	M	0.42	0.2	0	0
		20351	0.06	8	20	M	0.6	0.1	1	0
12	64500	20303	3.36	8	20	M	0.6	5.6	0	0
15	60000	20309	3.84	8	61	M	0.48	8	4	0
9	680000	20273	0.9	8	96	H	0.38	4.7	0	0
		20275	4.5	8	93	M	0.65	12.2	0	0
		20277	0.3	8	96	VH	0.66	0.82	2	0
		20279	1	8	96	VH	0.5	5.47	0	0
		20281	1.3	8	96	VH	0.55	4.28	0	0
		20283	1.47	8	96	VH	0.47	5.9	0	0
		20285	2.3	8	96	VH	0.45	9.6	0	0
		20287	1.6	8	96	VH	0.64	4.4	11	0
		20289	2.3	8	96	VH	0.65	6.15	16	0
		20291	2.9	8	96	VH	0.68	7.3	17	0
		20293	2.6	8	96	VH	0.63	7	29	0
		20295	3.3	8	96	VH	0.68	8.39	23	0
		20297	18.9	8	96	VH	0.53	57	157	0

D. Call market

Contact ID	Price	Patch#	HH	Bio	EVC	Sig	Score	Area	LOT	MOT
17	75000	20313	0	8	175	M	0	0	5	5
		20315	0	8	803	M	0	0	5	5
14	65000	20307	0	8	61	L	0	0	8	20
21	26200	20345	0	8	61	L	0	0	1	5
18	145000	20317	0.0224	8	61	L	0.28	0.08	0	0
		20319	0.0756	8	61	L	0.28	0.27	0	0
		20321	0.0102	8	61	M	0.34	0.03	0	0
		20323	0.007	8	61	M	0.35	0.02	0	0
		20325	0.012	8	61	M	0.3	0.04	0	0
		20327	0.0364	8	61	M	0.52	0.07	0	0
		20329	0.0273	8	61	M	0.39	0.07	0	0
		20331	0	8	61	M	0	0	7	5
25	26300	20369	0.0384	8	61	M	0.48	0.08	4	0
13	31500	20305	0.5712	8	61	M	0.48	1.19	3	0
30	54600	20411	1	8	175	M	1	1	0	0
24	46500	20361	0.715	8	20	L	0.55	1.3	1	0
		20363	0	8	61	L	0	0	6	5
		20365	0.084	8	61	M	0.42	0.2	0	0
		20367	0.06	8	20	M	0.6	0.1	1	5
11	13100	20301	0.29	8	61	L	0.29	1	0	0
22	31700	20347	0.715	8	20	L	0.55	1.3	1	0
		20349	0.084	8	61	M	0.42	0.2	0	0
		20351	0.06	8	20	M	0.6	0.1	1	0
12	64500	20303	3.36	8	20	M	0.6	5.6	0	0
15	60000	20309	3.84	8	61	M	0.48	8	4	0
8	13300	20265	0.7	8	61	H	0.64	3.39	2	0
		20267	0.1	8	61	M	0.56	0.69	0	0
		20269	0.1	8	61	M	0.55	0.37	1	0
		20271	0.8	8	61	M	0.54	5.21	0	0
6	44500	20253	0.199	8	22	M	0.49	0.92	2	5
		20255	0.867	8	20	M	0.63	3	2	5
		20257	2.753	8	61	M	0.59	10.01	6	5
3	60000	20229	1	8	67	H	0.48	3.68	1	5
		20231	0.832	8	67	VH	0.55	2.9	2	5
		20233	0.345	8	68	VH	0.61	1.14	22	5
1	19500	20217	0.108	8	67	H	0.42	0.62	0	5
		20219	0.429	8	67	0	1	4.04	0	0
		20221	0.088	8	68	VH	0.43	0.45	5	5
7	64000	20259	0.06	8	72	H	0.39	0.23	9	0
		20261	0.66	8	72	H	0.24	3.93	36	5
		20263	1.16	8	72	0	1	10.53	2	0