Evidence Based Farmer Decision Models to Assess the Potential for Multiple Benefit Carbon Trading

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Abstract

Planning efforts in the SA Murray Darling Basin (SAMDB) have focused on the revegetation of degraded, privately held agricultural land, using locally native species, to meet prescribed resource condition targets of increased biodiversity, carbon sequestration, salinity and wind erosion reductions. Revegetation costs are incurred by the individual, whilst benefits accrue primarily off farm and are shared by the wider public. The multiple benefits of revegetation constitute a common pool resource, characterised by costly exclusion and subtractive consumption. Current fixed or shared payment schemes to compensate individual costs have yielded relatively minor contributions to resource condition targets.

As an alternative, market based approaches are increasingly endorsed as a class of policy instrument to motivate land management actions that are economically rewarding, stimulate persistent innovation and make substantial contributions to policy objectives. Previous research indicates the hypothetical removal of extant institutional constraints, prohibiting access to an international CO_{2e} market, as the most cost effective and feasible instrument to promote large scale revegetation efforts. *A priori* evaluations of market based policy initiatives are often founded on normative behavioural parameterizations of profit maximization and optimal responses to available information. Failure to account for heterogeneous attitudes and motivations and variable willingness and capacity to participate, manifest as levels of revegetation, may result in reduced instrument performance with an attendant social cost. We paper describe an evidence based calibration of a conceptual simulation of heterogeneous dryland farmer attitudes into landscape scale natural resource management (NRM) planning. Spatially referenced attitude and behavioural profiles at the farm scale were characterized using a combination of spatial correlation, principle components and cluster analysis of survey responses of 593 dryland farmers (N=1084). We identified four significant farmer attitude segments. Regression models and structural equation modelling were unable to reliably establish the influence of attitudes, and as corollary, policy incentives, on revegetation behaviour. As an alternate method, we designed controlled economic field experiments, simulating the biophysical, economic and policy decision environment facing SAMDB dryland land mangers to elicit the magnitude and timing of revegetation of actual landholders subject to controlled framing of visual cues of near neighbour and catchment wide farm actions. Experimental results enabled the estimation of a spatial autocorrelation function of land management actions with near neighbour decision making when that information is made available.

The combined results improved the enumeration of the relationship between statistical attitude and behavioural classes, expressed as farm scale land management actions. We describe a spatially explicit multi-attribute model of farmer utility functions within a dynamic simulation environment. Levels of agent innovation, adoption rates, response to public disclosure of agent actions, near neighbour effect and revegetation efforts were evidence based according to the survey and experimental results. Fifty year landscape futures were simulated by modelling farmer responses to changes in six NRM policies.

These policy perturbations influence attitudes, and in turn revegetation actions, which determine farm economic viability and the magnitude of aggregate contributions to regional natural resource policy targets. Policy models reliant on a single instrument did not optimise for all multiple benefits. We conclude that a portfolio approach combining both market and non-market instruments is the preferred strategy. Modelled combinations maximised individual benefits, multiple common pool resource targets and an attendant global contribution to carbon sequestration. The results provide an evidence based *ex ante* assessment of the biophysical, economic and social impacts of market based policy initiatives to encourage carbon trading at dryland farm and catchment scale in the SAMDB.

Keywords: *natural resource management, decision making, experimental economics, agent based modelling*

1. INTRODUCTION

The clearance of native vegetation for agricultural development in the South Australian Murray-Darling Basin (SAMDB) NRM Region, inclusive of the River Murray, has lead to environmental problems such as biodiversity degradation, wind erosion and increased salinity via connected groundwater systems in the River Murray. The SAMDB (Figure 1) covers an area of 5.6 million ha and has been subject to land clearance and agricultural development for more than 80 years.

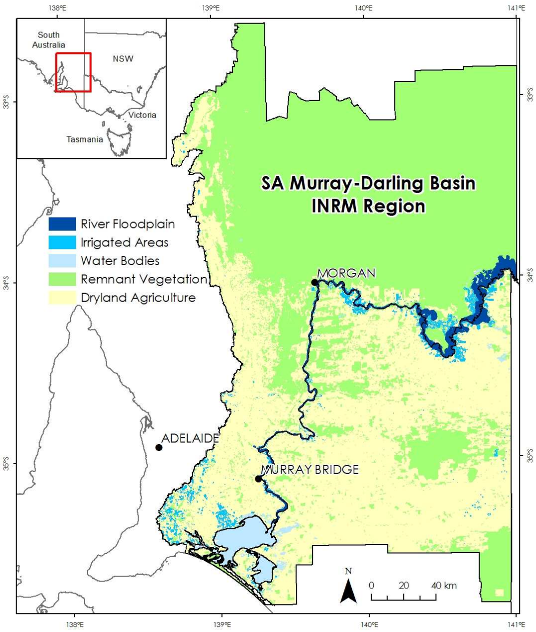

Figure 1. Location map and land use in SAMDB.

The SAMDB Integrated Natural Resource Management Group has identified the major environmental assets and threatening processes in the region and articulated a set of aspirational resource condition targets (RCTs) to address these threatening processes. The paper discusses the potential role of a carbon market in motivating land use change that contributes to the RCTs, methodologies to estimate likely adoption rates and the use of evidence based agent based models to test NRM policy options. We focus on the objectives of reduced salinity of the River Murray, improved biodiversity, carbon sequestration and reduced wind erosion [INRM Group 2003, Ward *et al*. 2005].

Analysis was restricted to dryland (non-floodplain, non-irrigated) agricultural areas where the dominant land uses include the cropping of cereals and legumes, the grazing of natural and modified pastures, and of native vegetation by livestock, mainly sheep. The mean area of SAMDB dryland cropping/grazing properties is 2407 ha, ranging up to 105,218 ha in the lower rainfall zones. A primary challenge for natural resource policy makers has been the implementation of cost effective instruments that motivate behavioural change and subsequent regional land management actions, resulting in both predictable environmental outcomes and sustained farm incomes. The revegetation of cleared, privately owned agricultural land with locally native, deep rooted, woody or broad-scale perennials has been widely promoted as an alternate remedial approach, providing multiple resource benefits and attributes [Bryan *et al.* 2007, INRM Group 2003, Ward *et al*. 2005]. Current estimates indicate the scale of revegetation necessary to meet the RCTs is spatially extensive and associated with high establishment and private opportunity costs [Bryan *et al.* 2007]. The scale of revegetation has fallen far short of the levels necessary to meet the resource objectives when motivation for land use change has been reliant on traditional policy instruments such as regulatory, statutory and legal remedies and uniform payment for input action.

The primary reason cited for insufficient levels of revegetation is that farmers are unwilling to undertake substantial investments in land use when the establishment of locally native species is costly and there is a long term loss of revenue from changing land use to revegetation. Whilst the private landowner generally incurs the costs of establishment, many of the NRM benefits are often realised over long time periods, carry some uncertainty of impact, and accrue predominately off-farm to the wider community who do not share in the initial investment costs.

The challenge for natural resource management policy makers is to introduce cost effective instruments that stimulate behavioural change and land management actions, resulting in predictable environmental outcomes. Policy objectives will also seek to clarify the assignment of risk, circumstances of compensation with non-controversial settlement and address the management of externalities. Instruments should also pass the conventional tests of efficiency and fairness in a changing world. In meeting those challenges, policies seek to promote regional management actions that both maintain economic returns to the farmer and contribute to the sustained increase in environmental assets or reduce environmental threats articulated in the resource condition targets. To encourage increased participation by private land holders in the SAMDB, successful policy aims to:

- motivate persistent land use change appropriate to the specified resource condition;
- encourage change at scales that contribute substantially to resource targets;
- mobilise high levels of participation in strategically beneficial localities and,
- achieve targets at the lowest cost to society.

The multiple, jointly produced environmental benefits associated with revegetation can be classified as a common pool resource, partially characterised by enforceable, excludable and transferable rights to utilise a defined extraction or appropriation of private land. A substantial component of revegetation confers a mutually shared, environmental benefit to both owners and non-owners of those extractive rights, which is both costly to exclude beneficiaries (a characteristic shared with public goods) and subject to rival or subtractable consumption (a characteristic shared with private goods). When joint outcomes depend on multiple actors contributing inputs or actions that are costly and difficult to quantify and policy instruments are deficient in promoting contributions, incentives exist for individuals to act opportunistically, often appropriating to a level where aggregate overuse and reduced benefits occur. A social dilemma occurs when individuals are tempted by short term gains to over appropriate the common pool resource, thereby imposing group shared costs on the common pool community (Ostrom 1998). Individual under contribution will eventually lead to reduced benefits for all.

Since the mid 1990's, market based instruments (MBIs) have been increasingly endorsed across an array of agency jurisdictions as effective policy instruments to address environmental targets at a more affordable cost to society [Tietenburg and Johnstone 2004]. MBIs encourage behavioural change through the price signals of markets, as opposed to the explicit directives for environmental management associated with regulatory and centralised planning measures [Stavins 2003]. The primary motivation of market based instrument approaches is to make environmentally appropriate behaviour more rewarding to land managers. It then follows that the best private choice will correspond to the best social and environmental choice.

Markets are attractive because of their ability to coordinate and truthfully reveal private information. They are effective economisers of information, expressed as precise price signals [Smith 2002] and coordinators of collective action. Bowles and Gintis [2004 p. 385] posit that when comprehensive and coherent contracts can be drawn and enforced at low cost, markets are superior to other governance structures. "*Where residual claimancy and control rights can be aligned, market competition provides a decentralised and difficult to corrupt mechanism that punishes the inept and rewards high performers"*. In contrast, the state is relatively well suited for handling particular classes of problems where it alone has the power to make and enforce the rules that govern the interaction of private agents: e.g. if participating is mandatory (public health and education and defence). Ostrom [1998] and Ostrom *et al*. [1992] articulate an alternative arrangement, proposing that common pool resources can be effectively managed if information, communication and sanctioning options are available to those using the resource. Communities can resolve common pool dilemmas that states and markets are not well equipped to manage, especially where the nature of social interactions or the goods being transacted makes contracting, exclusion or enforcement highly incomplete or costly. Adjudication relies on the revelation of dispersed private information unavailable to the state in concert with formal (often socially crafted) institutions to apply rewards and punishment to members according to their conformity with or deviation from social norms. Communication promotes conditional reciprocity; sanctions reinforce the social compact through reputation. Socially crafted compacts are reinforced by self monitoring, strong reciprocity or conditional cooperation and a series of escalating, credible sanctions.

From an ideal economic perspective it would be possible to determine the optimal scale of land use change, ensuring that the additional environmental benefits outweigh estimated costs. However, estimates of the economic value of environmental benefits gained are often only partial, rudimentary and of variable reliability. This has meant that answering questions on the relative merits of the cost effectiveness of policy choices and instrument design to achieve land use change of this magnitude have not been made with much precision or certainty. Several commentators note that MBI are not widely viewed as a panacea: recent developments in instrument design have recognised that successful MBI schemes have not necessarily substituted for regulatory approaches but are more generally complementary [Stavins 2003, Tietenburg and Johnstone, 2004, Tisdell *et al*. 2004, Young *et al*. 1996]. In many cases MBI may be advantageous, but in others the relative advantages over other instruments may be limited, poorly defined, state contingent and subject to change through time. For example a market based instrument may be cost effective, but may not perform well in the dimensions of adoption rates, administrative and transaction costs, concentration of environmental consequences and political feasibility. When these are important policy objectives, the single model terrain of economic efficiency or cost effectiveness may not be sufficient to reliably inform policy makers of instrument performance

Ward *et al*. [2005] estimated that the elimination of institutional barriers to carbon trading was the most promising MBI for the SAMDB. Revegetation with locally native mallee species, associated with substitute carbon trading revenues, offered an alternative farming system that is both commercially viable and of sufficient scale to meet the RCTs. At a carbon price of €5.45/tonne CO_2, carbon production was estimated to be more profitable than current agricultural practices on approximately 115,000 ha of land in the SAMDB. This represents an increase in the extent of vegetation of 3.7%, which is well in excess of the 1% revegetation target found in the SAMDB NRM Plan [INRM Group 2003]. At a carbon price of €10/tonne, the increase of 1,897,763 ha in revegetation represents a 61% increase, with associated carbon offsets of 3.58 million tonnes per annum.

2. ECONOMIC BEHAVIOUR

Most of the cleared areas and substantial areas of remnant vegetation in the study area are privately managed for agricultural production. Hence, farmers play a key role in NRM. Meeting regional RCTs depends upon the sum total of diffuse agricultural production and land management decisions made by individual farmers. Decisions made by farmers in the SAMDB affect the extent, intensity, and types of agricultural production. They also determine the extent and type of NRM actions undertaken including vegetation management, revegetation, the adoption of conservation farming techniques (no till) and alternative farming systems (e.g. agroforestry).

Farming is predominantly a business enterprise in the SAMDB. Land management decisions by farmers are dominated by expected economic returns, tempered by attitudes to risk. Models of farmer decision making are commonly used to predict changes in agricultural production and associated economic and environmental impacts. These models are often based on the idea of a homogenous cohort of farmers, acting as self-interested, rational economic actors and utility maximisers who optimally respond to available information, providing the normative foundation of economic modelling and modern policy analysis. However, this normative foundation of economic modelling has been under increasing scrutiny for failing to predict key facets of observed economic behaviour [*inter alia* , Sen 1977, Kahneman and Tversky 1979, Starmer 2000, Ostrom 1998, Gintis 2000, Kahneman and Sugden 2005].

Camerer *et al*. [2004] summarises numerous augmentations to expected utility theory to improve normative capacity and explain the predictive and observed discrepancies. Two key tenets have been explored: the infallibility of human cognition and the expression of other regarding behaviour. Simon [1972] proposes a contextual bounding of rational behaviour as a theoretical buttressing to the first point, expressed pragmatically by Plott [1996] and Bimore [1999] as the discovered (or deferred) preference hypothesis. That is observed deviations represent temporary, non-systematic cognitive lapses, in contrast to theoretical and systemic violations. Gintis [2000, 2008] and Sen [1977] propose that the inclusion of other regarding behaviour in a welfare function, contextually quantified and correlated, provides a coherent and consistent basis for a more robust economic analysis, without jettisoning the entire analytical model. Kahneman (2003) and Camerer *et al.* [2004] review empirical studies that document behavioural digressions from modelled predictions of specific domains of behaviour. Despite these research endeavours, the debate remains contentious, vigorous and durable and a tension remains between the single metric Pareto efficiency terrain, ubiquitously applied, and the need for a syncretic, multi attribute inclusion of utility. If key proportions of the population systematically fail to adhere to the antecedents which give policy analysis practical capacity and validity, a systematic investigation of the predictive failings of the tenets of the rational economic model assumes increasing importance.

This discrepancy is often expressed as low landholder participation rates in programs deploying market instruments. Pannell *et al*. (2006) argue that individual decision making and adoption levels within an agricultural and natural resource management context is partially contingent on a number of complex interacting factors. These include heterogeneous risk preferences, the influence of social norms and tradition, pro-social and environmental preferences, institutional transition, variable capacity and willingness to innovate, the ease and predictability of land use change, relative economic advantage and the effectiveness of communicating the economic benefits of new farming systems relative to current agricultural production [Vanclay 2004, Cary *et al*. 2002]. These cognitive deviations from normative predictions are regularly omitted from models [Kahneman 2003]. The outcome may be that the opportunities and benefits that MBIs potentially offer are either not fully realised or over estimated [Harrington 2004].

Vanclay [2004] and Pannell *et al*. [2006] argue for a more comprehensive set of modelled market impediments and behavioural motivations to better evaluate the likely cost effectiveness of MBIs in Australian rural settings. Farmers' perceptions of the relative importance of MBIs are informed by their personal constructs, attitudes or cognition about farming [Azjen 1991]. Thomson [2005] and Curtis *et al.* [2003] employed a 'farming styles' approach based on Azjen's theory of planned behaviour to derive an understanding about groups of farmers who share similar attitudes and subsequent land management behaviours. We propose a conceptual modelling framework that considers many of these aspects of potential heterogeneous farmer decision making with regard to the testing of alternate NRM policy options in the SAMDB.

3. METHODS

A number of modelling tools and techniques were combined to analyse this complex problem including Geographic Information Systems, Benefit-Cost Analysis, and Multi-Criteria Decision Analysis [Bryan and Crossman 2008]. In this paper we focus on the farmer decision making module which we formulate as a spatially explicit multi-attribute model of farmer utility within a dynamic simulation environment [Ligtenberg *et al.* 2001, Parker *et al*. 2002]. We describe an evidence based calibration of agents' farm management behaviour using the results of a mail out questionnaire and contextualised experimental economics.

3.1. Characterising farmer decision profiles

Dryland farmers were surveyed to provide an empirical basis for the multi-attribute utility functions underpinning the farmer decision models (Ward *et al.* 2007). A census approach was employed, with a mail-out questionnaire to all 1,142 dryland farmers (with properties >10 ha) in the SAMDB. GIS was used to identify the cadastral boundaries of all dryland properties in the SAMDB. Spatially referenced data layers indicating associated agricultural activities, estimates of extant opportunity costs, areas of remnant vegetation and estimates of contributions to dryland salinity, levels of biodiversity and wind erosion were annexed to cadastral data [Bryan and Crossman 2008, Ward *et al*. 2005].

The objective of the survey was to identify significant farmer segments in terms of likely participation in, and behavioural responses to, market based approaches to motivate changed farming practices [Curtis *et al*. 2003]. Scale items were designed to elicit business, individual knowledge, perceived control (capital, time, empowerment, social norms), risk, technological innovation, learning, natural resource management and environmental responsibility and attitudes. Behaviour scales were developed according to farm planning, accounting, computer skills and use, farm and soil management, market practices, sowing practices, vegetation management, planting and remnant revegetation aspirations and scheme participation (e.g. Landcare). A suite of demographic variables were also included. The questionnaire was pre-tested in an area adjacent to the SAMDB, characterised by similar dryland farming regimes, land management actions and agricultural pursuits [Thompson 2005]. The mail survey was administered using a modified Dillman *Total Design Method* and follows the method used by Curtis *et al*. [2003] to explore spatially referenced landholder responses to salinity in a proximate region.

Fifty-eight responses of 1,142 questionnaires were excluded from the original sample, leaving a sample frame of 1,084. The remaining 593 valid responses (54.7%) were included in the analysis. Principle components factor analysis (varimax rotation) identified seven latent variables (23 of 51 scale items) reducing variable dimensionality by 66%. These were, in order of variance explained: profit motivation; innovation; perceived control capital constrained; environmental attitude; tradition; time and willingness to learn, and; social influence on decisions. The seven attitudinal constructs identified explained 62% of data variance. All are characterized by an Eigen value > 1.0 and variable factor loadings >0.60. Four discrete farmer profiles were identified by hierarchical cluster analysis of the factor scores. Clusters were characterized by between segment mean Eigen value distances of 3.205 – 10.174. Anova indicated significant differences (LSD *post hoc* test, p<0.05) between clusters for all constructs, in addition to current revegetation management ($F_{593,3}$ =5.717), and non-construct variables including desired levels of revegetation in 10 years ($F_{593,3}$ =8.750) and 50 years ($F_{593,3}$ = 11.882). Based on cluster membership and Anova results, clusters can be described as (% of sample in brackets):

1. *Socially influenced farmers* (51.9%): low profit motivation, lowest environmental attitude, high level of social influence on decision making.
2. *Innovative farm business managers* (25.2%): high profit motivation, most innovative, traditional, not capital constrained or motivated to learn, indifferent to social influence on decision making. 31% of all respondents were classified as highly innovative (composite score of > 13 out of a possible 15).

3. *Life style hobby farmers* (10.1%): lowest profit motivation, highly environmentally motivated, not capital constrained or motivated to learn and not socially influenced.
4. *Time and capital constrained conservation manager* (12.8%)*:* highly capital constrained, highly motivated to learn, highest environmental attitudes and not socially influenced in decision making.

SAMDB NRM policies seek to motivate persistent land use change (viz. revegetation behaviour) appropriate to the specified RCTs. Farmers' perceptions of the relative importance of these incentives are informed by their personal constructs, attitudes or cognition about farming. The primary objective of the survey was to estimate the relationship of current revegetation behaviour and elicited attitudes and intent. The following OLS equation describes the estimation of observed variance of current revegetation for individual farm *i*:

$RB_i = Att_i + I\beta_i + Sn\Sigma_i + PC_i + Opp_i + wRB_j$

Where for farmer *i*:

RB_i = current revegetation behaviour
Att_i = vector of attitudes (Σ loaded scales)
$I\beta_i$ = intended revegetation action
$Sn\Sigma_i$: = influence of social norms on *i* decision making
PC_i = vector of perceived controls
Opp_i = current opportunity cost
$w\beta_j$ = decayed weighted influence of nearest neighbour *j* for behaviour RB and w = 1/distance *i-j*

Fitting the above equation to the data resulted in an $R^2 = 0.10$, $F = 5.488$ ($p<0.05$) indicating 10% of variance in stated revegetation behaviour was explained by variance in explanatory variables. The Durbin-Watson statistic $d = 2.03$ (n=583, k= 13) indicates there is no significant residual serial correlation ($p \geq 0.05$). The results are in contrast to those expected according to Ajzen's theory of planned behaviour. As the survey results were spatially referenced, we tested for both spatial auto-correlation and lag as an explanatory variable. Anselin's [1995] likelihood ratio test indicated there was no significant spatial auto correlation for the index of aggregate revegetation actions, localised according to variable $w\beta j$ ($\lambda = 0.308$, p=0.58). Localised Moran's I spatial autocorrelation statistic was not significant ($p \geq 0.05$) for the four aggregate attitudinal constructs.

3.2. Field Experimental Economics

Traditional survey techniques failed to establish a relationship between attitudes and revegetation actions, precluding populating agent based models with survey based data. As an alternate method, we designed a controlled field experiment that allowed survey respondents to create carbon credits through revegetation actions, and sell carbon credits in a simulated international carbon market. The experiments were held using a mobile wireless LAN computer laboratory using the MWater experimental software (2007) at Waikerie and Murray Bridge, two central locations in the SAMDB. Twenty-four survey respondents enrolled at one of the two locations. Experimental sessions were comprised of 12 experimental farms, characterised by heterogeneous values of production and carbon sequestration and three independent repeated round (n=10) experimental treatments. The number of experimental participants for each cluster segment was scaled up by a factor of five to ensure a minimum of five members per cluster. The Chi squared test indicated there was no significant difference (χ^2=0.633, p=0.889) between the experimental cluster membership frequencies compared to the cluster frequencies of the aggregate sample cohort.

The field experiments were developed to: a) measure observed changes in land actions when farmers are able to substitute farm income with carbon trading income; b) estimate the mathematical relationship between attitudes and behaviour to calibrate agents, and; c) spatially describe the effect of near neighbour actions on land management and trading behaviour (to address the social influence of decision making observed in Cluster 1 or 51.9% of the sample).

The three experimental treatments were: T1) represented a control whereby players were only provided the farm decision in numerical form (1-5), the income, number of carbon units and the marginal value ($/tC) for each decision; T2) as per T1) + Action (a description of the framing decision i.e. traditional-native veg), and; T3) as per T2 + a visual cue or framing reference of the decisions that other players had made in the previous period (Figure 2). The visual cue spatially references the farms in the SAMDB and players were only advised of the location of their own farm. The visual cue was projected on screen at the end of each trading period. Icons (Figure 2) indicated individual land management decisions.

Carefully designed instruction sets, specific for each treatment were provided via individual internet access to a power-point display. The instructions explain the farm characteristics, decision sets, rules, protocols and payments specific to each experimental treatment (available form the corresponding author). Supervising staff did not verbally present the instructions to avoid personality or behavioral biases and correct for possible delivery nuances. Talking, unless formalized in the treatment, was forbidden except to clarify questions from individuals regarding the experimental setting or instructions. To control for variable learning and to ensure consistent understanding, participants were required to accurately answer a quiz comprising of 7 questions specific to the experimental treatment. The successful completion of the quiz was a necessary prerequisite for participation in the experiments.

Table 1 Typical experimental farm

Action[2]	**Decision**[1]	**Income ($/10 ha)**[1]	**carbon (t/10ha)**[1]	**carbon ($/t)**[1]	**Optimal $/10 ha @ $50 /t C**
Traditional	1	1156	0		1156
Biofuels	2	2063	0		2063
Biomass	3	771	7	54	1130
50% Traditional + 50% native veg	4	578	15	38	1334
Native veg	5	0	30	38	1511

[1]: information for T1 (control) [2]: additional information for T2 and T3

Where possible, each participant was assigned to an experimental analogue of their actual property, standardised to a farm size of 10 ha, and selected from five possible farm management and revegetation options. Table 1 describes a typical experimental farm. The 12 heterogeneous experimental farms represent a scaled version of existing farms, characterised by farm income, carbon productivity and the marginal value of a carbon credit (tonne) specific to each of five farm management decisions (see Bryan *et al*. 2007 for details). Options characterized by higher income levels were associated with lower carbon levels for all farms. The Biofuel option (decision 2) was characterized by high income associated with a probability of crop failure (zero income) of 0.5, determined randomly for each period. Each session involved 10 independent, replicate periods of annual management decisions followed by market trading in sealed offer, 1st price uniform clearance market. A single buying agent placed an order of $50/tonne carbon (equivalent to the prevailing market price of €22/tonne CO_{2e}). Participant terminal screens were updated after each period with player income and market price and quantity successfully traded. Player income was automatically calculated.

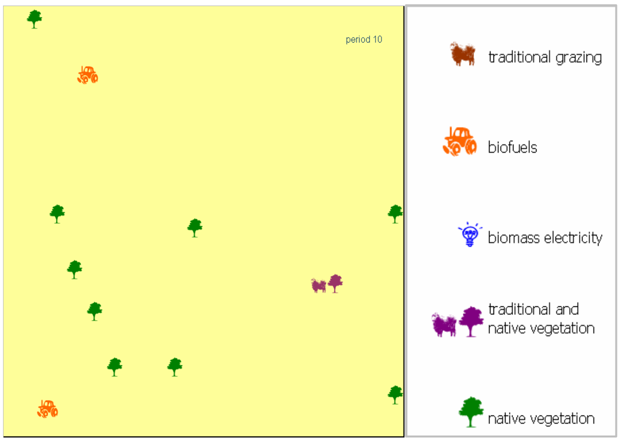

Figure 2 example of the visual cue illustrating icons of catchment wide farm decisions and spatial location of individual experimental farms

Players were paid a scaled representation of the income decisions confronting dryland farmers in the SAMDB to ensure salience of player behaviour and response to income variance in the simulated catchment. In addition to a $10 attendance payment, specific farm (player) payments were rescaled using a payment schedule of $5.00 per period for achieving the derived optimum farm income and $1.00 for the low income traditional farming decision. From Table 1, a farm income of $1511 (farm decision 5 and attendant successful carbon trading of 30 carbon credits) is equivalent to a $5 period payment.

3.3. Experimental Results

Mixed linear model analysis indicated there was no significant random interaction or nested effects of periods and treatment (Wald z redundant or P>0.05). Periods were treated as independent data points for analysis. Compared to T1, the total carbon credits produced and successfully traded significantly increased at both locations (t = -3.396, p<0.05). Aggregate income also increased in T3 compared to T1 (t= -1.107, 0<0.10). Table 2 summarises the experimental results for T1 and T3. There was no significant difference (P≥0.05) in carbon or income between T1 and T2.

Table 2 Observed carbon credits and income for T1and T3.

	Carbon (tonnes)			**Income ($)**		
	T1	T3	increase	T1	T3	increase
Waikerie	1782	2194	23% *	526	539	3%
Murray Bridge	1870	2190	17% *	454	547	20% *

* significant at p<0.05

Experimental data were used to estimate the social influence on individual decision making. The effect of the visual cue T3 (near neighbour decision making) was compared to T1 (no visual cue). The spatial autocorrelation of traded carbon between player *i* and other players *j* was estimated using ArcGIS simple kriging (circular model) for variable S where S = C_5-C_4 for player *i* and C_4 for $\forall$ player *j*. C = the ratio of observed traded carbon to carbon credits produced by Decision 5 (optimal). C_5 and C_4 represent periods 5 and 4 respectively. The mean range of players 1-12 for T1 (157 km) was significantly less than that of T3 (76 km; t= 4.341, p<0.001). The root mean square standardised approximated one in all cases. The mean spatial autocorrelation of the influence of nearest neighbour (SI) was estimated by the function SI= 0.10626 x 76 + 0.06 (spatial nugget).

4. DYNAMIC SIMULATION MODELS

Dynamic simulations employing cellular automata were modelled for six revegetation policy options over a 50 year time horizon across a sub-region of the SAMDB (Figure 3). The prioritisation model specifications for changes in biodiversity, carbon sequestration, drainage reduction, wind erosion reduction and risk prioritisation are described in Bryan and Crossman [2008], Bryan et al. [2008] and Bryan *et al*. [2007, ch 11]. At the farm scale, 636 independent cellular automata or agents selected 1 ha/year for revegetation over 50 years, according to six simulations of various policy prescriptions. Outcomes were measured as the aggregate of all agents for the area revegetated, aggregate cost, biodiversity, wind erosion and salinity reduction.

Cellular automata decision making was influenced by both random processes and algorithms imputing permutations of four key and interdependent variables; innovation, adoption, information dissemination and cost effective targeting. Innovation levels or the probability to be a first mover and adoption pathways, including neighbourhood information diffusion are ambient catchment characteristics rather than a specific class of policy instruments. Policy instruments are able to influence and direct the processes of information dissemination; in this case we incrementally impute levels of information on near neighbour revegetation decisions based on the experimental results and the cost effectiveness of specific hectares at the farm scale.

A null policy model was initially populated with data, agent characteristics and interrelationships based on prior assumptions on innovation and adoption levels. Five additional policy simulation models were calibrated incrementally with survey and field experimental data and results. Increased innovation levels in model iteration year 1 were imputed from the attitudinal survey results, estimates of adoption rates were imputed from the no visual cue and visual cue experimental results, and finally individual hectares selected annually for revegetation by individual agents were prioritised according to a discriminatory function of cost effectiveness.

The six policy prescriptions and associated algorithms are described below.

1. Policy model 1; Null model. 5% (n_{t1} = 19) of the agent population in year t=1 were selected randomly, acting as innovators or first movers likely to adopt revegetation with local species and subsequent carbon trading. Adopting agents selected the initial hectare for revegetation at random and revegetate an additional hectare contiguously with previous selected hectares for subsequent annual iterations. The Null model forces a minimum 50% revegetation adoption rate in year 50 ($n_{t50} \approx 314$). A non-innovative agent adopts revegetation if an adjacent agent has previously adopted. Agents were selected randomly if the number of adopting agents was less than a calculated level for year t, according to a hyperbolic function estimating the number of adopters A for year t, such that $A_{(\text{null})} = 0.6006t/(13.25t) + 0.0003t$.
2. Policy model 2; innovation. Null + 31% of population (t_1 = 199) randomly assigned as innovators and first movers in year 1, in accordance with the survey estimates. Adopting agents in years t_2-t_{50} annually revegetate an additional one hectare for each iteration as described in the Null model. Non-innovative agents adopted revegetation according to the same method described for Policy model 1, subject to the function $A_{(\text{innovate})} = 0.5564t/(0.775t) + 0.0012t$. The function was estimated by extrapolating the carbon traded data from field experiments for Treatment 1 (no visual cue) for 50 years. As individuals were constrained by quantity of carbon produced, the level of carbon traded was imputed as a surrogate value for adoption rates. The number of adopting agents in $t_{50} \approx 385$.
3. Policy model 3; access to information. Policy 2 + publicly disclosed information. The field experimental data for Treatment 3 (agents have access to visual information of other agent's land management decisions) was extrapolated to estimate the number of adopters A for year t according to the function $A_{(\text{information})} = 0.6541/(1.22t) + 0.003t$. The number of adopters in t_1 = 199 and $t_{50} \approx 505$. Agents in iteration t_1 were randomly selected as in innovation Policy model 2 and adopting agents revegetating single hectares annually were selected according to the Null policy model.
4. Policy model 4; near neighbour effects. Policy model 3 + increased probability of adoption if near neighbours have adopted. In addition to Policy Model 3 adoption conditions, the increased probability of agent adoption was calculated according to function SI= 0.10626 x 76 + 0.06; where x is the distance between agent and neighbour centroids.
5. Policy Model 5; cost effective selection (targeting) of revegetated hectares. Policy Model 3 + hectare selection determined as the most cost effective, estimated as the ratio of net benefits to net costs. Policy Model 5 is deterministic in hectare selection, in contrast to the random selection of revegetated hectares in models 1-4. Net economic returns were calculated in annualised net present value dollars per hectare per year. These dollar values were transformed into cost score layers

with units between 1 (low cost) and 5 (high cost), commensurate with other layers of environmental benefit, and calculated as:

$$C = \frac{\left(NER - \min NER\right) \times 4}{\left(\max NER - \min NER\right)} + 1$$

Where:

min *NER* = Minimum grid cell value of all net economic return layers for revegetation
max *NER* = Maximum grid cell value of all net economic return layers for revegetation

One of the characteristics of natural resource management actions that is capitalised on in this study is the ability of some land management actions to contribute to multiple environmental objectives and resource condition targets. To calculate the benefits of each natural resource management action for multiple objectives (*B*) the benefit scores for each environmental objective are summed such that:

$$B = B(B) + B(DD) + B(WE) + B(C)$$

Where:

B: represents biodiversity
DD: represents deep drainage (dryland salinity reduction)
WE: represents wind erosion
C: represents carbon sequestration

A multiple environmental benefits score was created through a linear transformation of raw values such that:

$$B = \frac{\left(B - \min B\right) \times 4}{\left(\max B - \min B\right)} + 1$$

Where:

min *B* = Minimum grid cell value of all benefit layers for revegetation
max *B* = Maximum grid cell value of all benefit layers for revegetation

To calculate priority areas for each natural resource management action, the cost score was divided by the multiple objective benefit score for each action:

$$Pr = \frac{C}{B}$$

6. Policy model 6; Policy model 3 + most cost effective selection of revegetated hectares.

5. MODELLING RESULTS AND POLICY ANALYSIS

Figure 3 illustrates the spatial distribution of revegetation resulting from the six policy options simulations at year t=50. Figure numbers 1-6 correspond to Policy Models 1-6. Graphics in the left panel indicate the number of total adopters, area of restoration and the opportunity cost respectively for period *t*. The right panel indicates the marginal change in carbon sequestered, biodiversity levels, wind erosion reduction and deep drainage or salinity reduction.

A random number generator determined the initial innovator/follower seeding of Agents in $t = 1$ and the selection of hectares to revegetate for Policy models 1-4. Monte Carlo analysis of 100 iterations of the 50 year simulation for all policy models was utilised to account for variation in simulation output due to random influence. The results of variable mean by year are illustrated in Figure 4 (1-5). Distributions for all variables were normally distributed (K-S test , $p<0.05$). Anova tests were used to compare the output variable means of the six policy models at year $t=50$, summarised in Table 3. Dunnett's *t3 post hoc* tests was used for pair wise comparison, (Levine's test of homogeneity of variance, $p=0.000$).

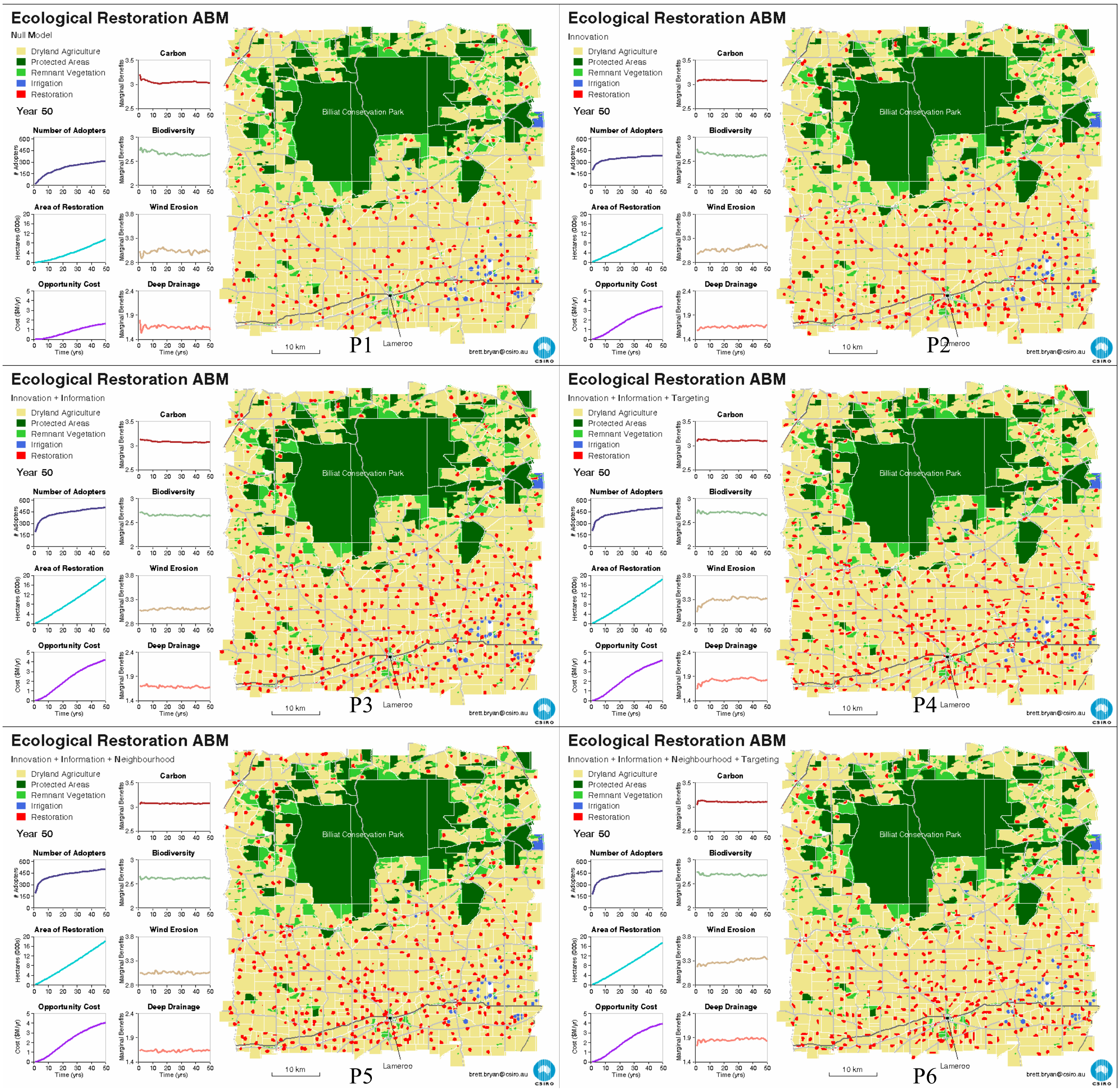

Figure 3 Graphic representation of dynamic agent simulations of six NRM policy outcomes after 50 annual iterations. The numbers 1-6 correspond to Policy models 1-6

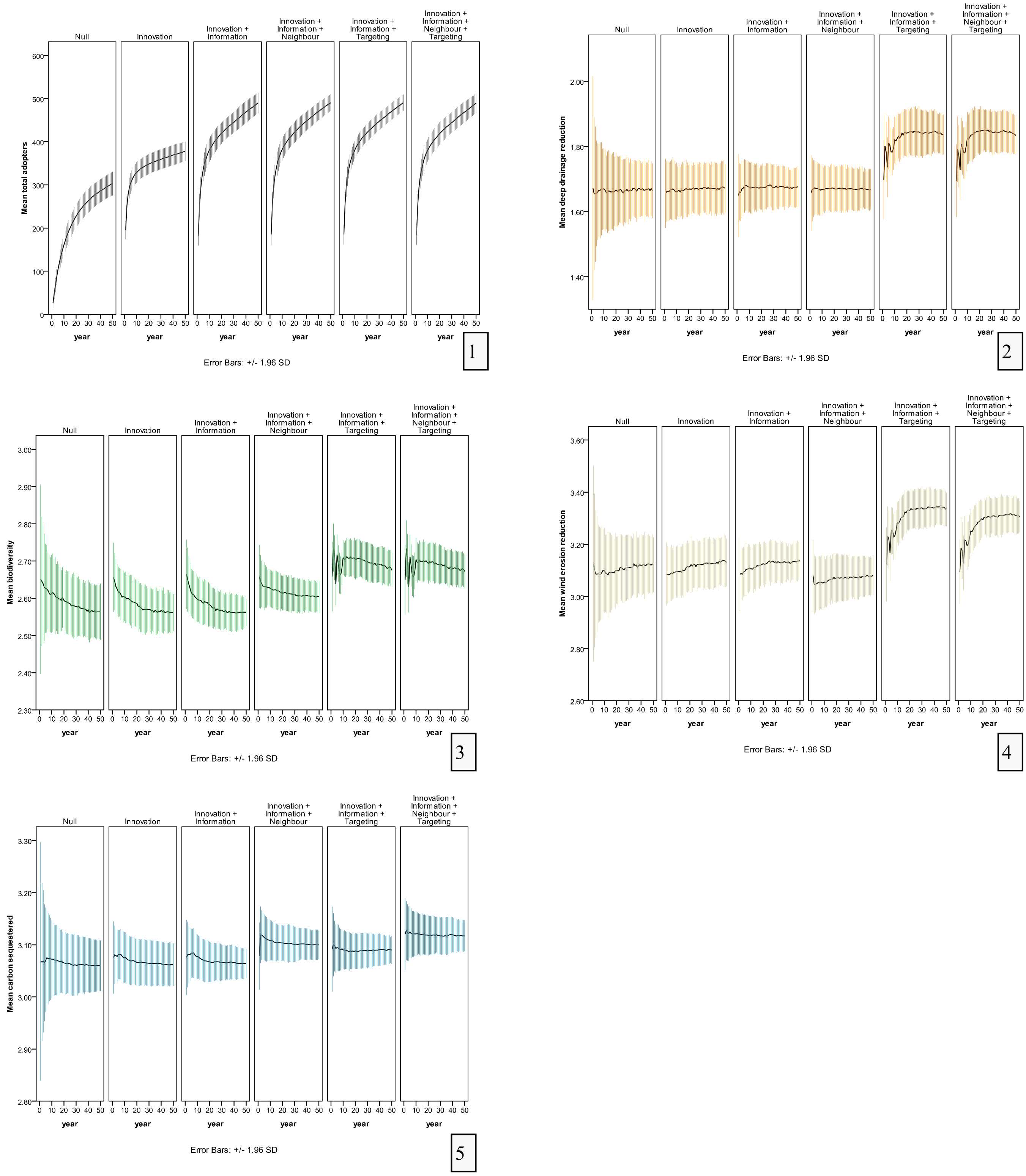

Figure 4 Graphic representation of *monte carlo* analysis of the outcomes of simulations of Policy models 1-6, after 50 iterations. Error bars represent ± 1.96 s.d. 1 = total adopters; 2 = deep drainage or salinity reduction or ; 3 = biodiversity; 4 = wind erosion; 5 = carbon sequestered.

Table 3 Anova of Monte Carlos analysis of six MRM policy models

	df	F	Sig.
Total adopters	5	5294.009	0.000
Total cost	5	5101.327	0.000
Total area	5	4987.792	0.000
Mean biodiversity	5	647.818	0.000
Mean carbon sequestered	5	592.460	0.000
Mean wind erosion	5	1289.857	0.000
Mean deep drainage	5	1321.670	0.000
Moran's I spatial auto correlation	5	1325.115	0.000

The increase in total adopters evident in Figure 4.1 illustrates an evidence based modelling artefact, estimated from the 31% innovation level observed in the survey results. The increase in total adopters in Figures 4.3-4.5 is a function of increases in revegetation action observed in the field experiments when visual cues of neighbour actions were made available. Neighbour effects were modelled according to experimental field results, imputing estimates of the vector neighbour distance (76 km) and the distribution of influence on the probability of adoption. Neighbour effects are endogenous to the modelled agent population and are not directly influenced by policy instruments.

Post hoc analysis of between policy model means revealed that the introduction of neighbour effects (policy model 4) significantly (all significance levels at $p<0.05$) reduces the mean level of salinity reduction compared to information only (policy model 3) and information + targeting (policy model 5). The singular reliance on modelled near neighbour effects when policy publicly declares information but excludes targeting results in a significant decrease in salinity reduction. Combining neighbour effects with targeting (policy model 5) does not significantly improve salinity reduction; similar results are depicted for wind erosion.

Policy model 5 significantly increases biodiversity contributions compared to policy model 3 and 4. Combining neighbour effect with targeting (policy model 6) does not significantly increase biodiversity contributions. In contrast, the probability of adoption modelled as neighbour effects in policy model 4 significantly increases the level of carbon sequestration compared to both policy models 3 and 5. Neighbour effects reinforce targeting, depicted in the combined instrument policy model 6, Figure 4.5, indicating a significant increase in carbon sequestration.

6. CONCLUSION

The combined results improved the enumeration of the relationship between statistical attitude and behavioural classes, expressed as farm scale land management actions. Cluster analysis of the field survey results identified four significant attitudinal segments characterised by differences in land management motivations and likely adoption rates. Regression models were unable to reliably establish the influence of attitudes, and as corollary, policy incentives, on revegetation behaviour. Analysis of the land management and carbon trading field experiments indicated that the reference frame of visual cues of player actions resulted in a significant increase in revegetation actions and the amount of carbon traded. Player actions were represented by a spatially referenced set of land management icons.

We have described a spatially explicit multi-attribute model of farmer utility functions within a dynamic simulation environment. Levels of agent innovation, adoption rates, response to public disclosure of agent actions, near neighbour effect and revegetation efforts were evidence based according to the survey and experimental results. Introducing an empirical foundation enabled a formal, evidence based recalibration of dynamic agent models testing the performance of the six NRM policy options in the SAMDB over a period of 50years. The initial null model assumptions of social diffusion model parameters of agent homogeneity, initial innovation levels and near neighbour effects differed significantly from models constructed from the survey and experimental results.

Policy instruments and stimuli influence attitudes, and in turn revegetation actions which determine farm economic viability and the magnitude of aggregate contributions to regional natural resource policy targets. Instruments implemented individually and in combination result in variable rates of revegetation adoption and levels of contribution to the regional resource condition targets of biodiversity, salinity reduction and reduced wind erosion as well as the global contributions to carbon sequestration. *A priori* analysis based on theoretical assumptions and heuristics did not predict the degree of variability in the performance of policy instruments and as a corollary the potential for the market exchange of tradeable carbon credits. The combination of methods, techniques and analyses described indicate there is no single instrument or policy terrain that simultaneously maximises the contributions of revegetation to all resource condition targets. The results suggest a carefully sequenced portfolio of instruments is required to achieve multiple policy objectives. The public disclosure of information (in this case visual cues), in concert with the diffusion vectors of near neighbour effects contributed significantly to the policy objective of increased levels of adoption. Spatial targeting at the farm scale enabled prioritisation of planting schedules, addressing the policy objective of increased contributions to regional resource condition targets. The portfolio approach, cognisant of high extant innovation levels, and incorporating, information provision and neighbour diffusion maximised common pool contributions and the potential for the market exchange of tradeable carbon credits.

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