The Potential for Carbon Trading In the SA Murray Darling Basin: Modelling Farmer Decision Making

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EXTENDED ABSTRACT

This paper describes an evidence based calibration of a conceptual simulation of heterogeneous dryland farmer attitudes into landscape scale natural resource management (NRM) planning. Planning efforts in the SA Murray Darling Basin (SAMDB) have focused on the revegetation of degraded, privately held agricultural land using locally native species with attendant biodiversity benefits and salinity and wind erosion reductions. Current payment schemes have yielded relatively minor contributions to prescribed 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 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 one of 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 quantities of revegetation, may result in reduced instrument performance with an attendant social cost.

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 visual cues of near neighbour and catchment wide farm actions. Results from experimental economics 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. Fifty year landscape futures were simulated by modelling farmer responses to changes in four NRM policies: a) random selection of spatial units, b) selection for the most cost effective NRM outcome, c) selection for the best biodiversity outcome and d) promotion of social diffusion to influence adoption rates. These policy perturbations influence attitudes, and in turn revegetation actions, which determine farm economic viability and the magnitude of aggregate contributions to specific regional policy targets.

The survey and experimental results enabled a formal, evidence based recalibration of agent models testing the performance of the four NRM policy options. The final step in the research project will recalibrate representative agents in the social diffusion model with these evidence based parameters. Heterogeneous agents will represent four attitude segments, the proportion of innovative agents in the initial model iteration will be increased from a previously assumed 5% to the observed 31% and the agents will be modelled according to the function of near neighbour effect.

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 SAMDB.

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.

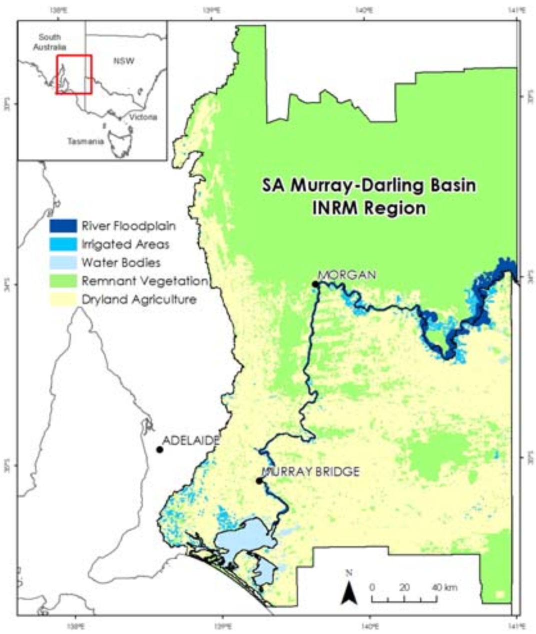

Figure 1. Location map and land use in SAMDB.

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 and reduced wind erosion [INRM Group 2003, Ward *et al*. 2005].

This paper focuses on the 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 up-front investment costs.

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.

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 farmers as self-interested, rational economic actors and utility maximisers who optimally respond to available information. However, this normative foundation of economic modelling has been under increasing scrutiny for failing to predict key facets of observed economic behaviour [*inter alia* Gintis 2000, Kahneman and Sugden 2005].

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 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 in press]. In this paper we focus on the farmer decision making module which we formulate as an agent-based model [Ligtenberg *et al.* 2001, Parker *et al.* 2002]. Our objective is 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

We surveyed dryland farmers to provide an empirical basis for the multi-attribute utility functions underpinning the farmer decision models. 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 in press, 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 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 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.
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 motivated by social influenced.

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*:

$$RBi = Atti + I\beta i + Sn\Sigma i + PCi + Oppi + wRBj$$

Where for farmer *i*:

RB*i* = current revegetation behaviour
Att*i* = vector of attitudes (Σ loaded scales)
Iβ*i* = intended revegetation action
SnΣ*i*: = influence of social norms on *i* decision making
PC*i* = vector of perceived controls
Opp*i* = current opportunity cost
*w*β*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 estimated variance in imputed variables. The Durbin-Watson statistic d = 2.03 (n=583, k= 13) indicates there is no significant residual serial correlation (p≥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 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 $w\beta j$ (λ = 0.308, p=0.58). Localised Moran's I indicated there was no significant ($p<0.05$) spatial autocorrelation 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 at Waikerie and Murray Bridge, two central locations in the SAMDB. Twenty-four survey respondents enrolled at one of the two locations, comprising three independent sessions of 12 participants. 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 51.9% of the sample).

The three experimental treatments were: T1) control where players were only given 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 decision i.e. traditional-native veg), and; T3) as per T2 + a visual cue or 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 decisions. Instructions were provided via individual internet access to a power-point display explaining the trading rules, protocols of the experimental treatment and the characteristics of the experimental farm (available from author).

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
Traditional native veg	4	578	15	38	1334
Native veg	5	0	30	38	1511

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

Where possible, each participant was assigned to an experimental analogue of their property, standardised to a farm size of 10 ha, selecting 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 was characterized by high income associated with a probability of crop failure (zero income) of 0.5, determined randomly for each period.

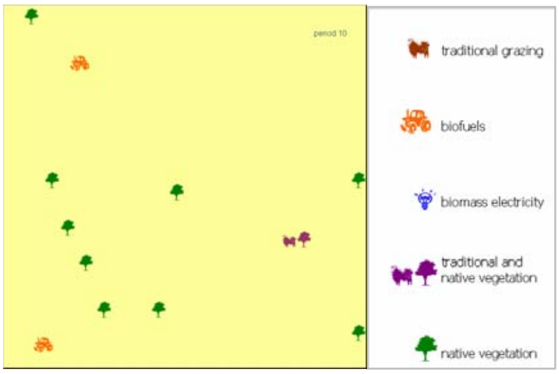

Figure 2 example of the visual cue illustrating catchment wide farm decisions.

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.

We paid players 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.

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%

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 ∀ 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 (nugget).

4. DYNAMIC SIMULATION MODELS

Dynamic simulations were modelled for four revegetation policy options over 50 year time horizon across a sub-region of the SAMDB (Figure 3). At the farm scale, the policy algorithm selected for:

a) Random sites;

b) The most cost effective sites for a positive NRM outcome;

c) Sites for a best for biodiversity outcome, and;

d) Hectares revegetated according to social diffusion function. 5% of agents were modelled as innovators and early adopters of revegetation of 1 ha in year 1. Non- innovator agent i adopted revegetation from year p, if contiguous neighbour(s) j revegetated in year p-1.

The model specifications are described in Bryan and Crossman [in press], Bryan *et al.* [2007] and Ward *et al.* [2005]. Farm scale agents selected 1 ha/year for revegetation according to the policy prescription, and outcomes were measured as aggregate area revegetated, aggregate cost, biodiversity, wind erosion and salinity reduction.

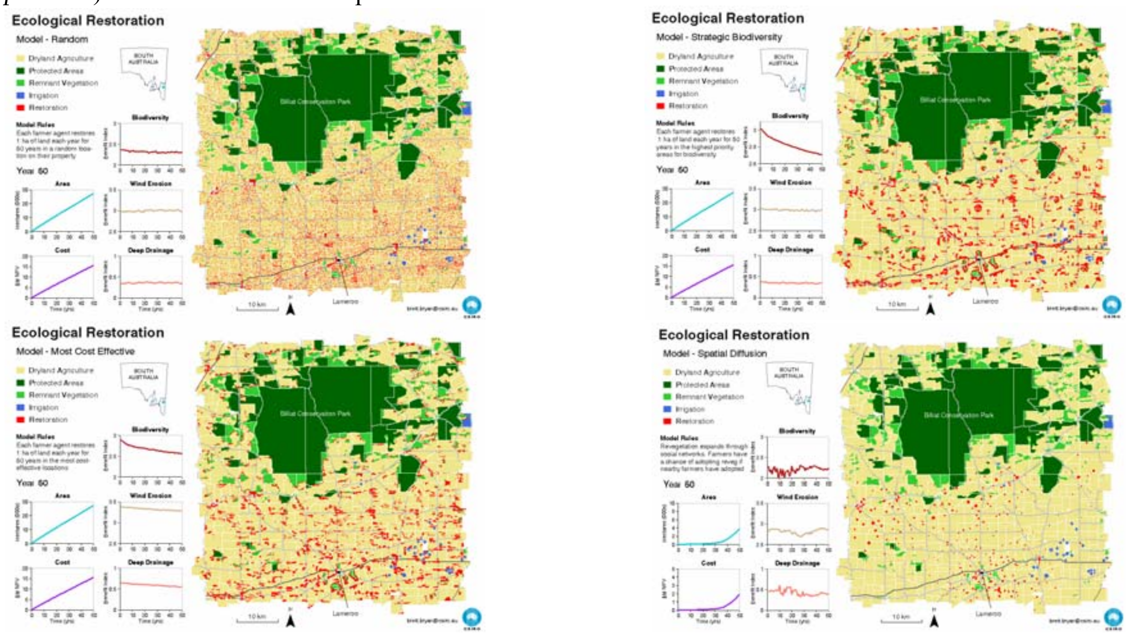

Figure 3 Graphic representation of agent models of four NRM policy outcomes after 50 annual iterations.

5. CONCLUSION

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. The survey and experimental results enabled a formal, evidence based recalibration of agent models testing the performance of the four NRM policy options in the SAMDB over a period of 50years. The original social diffusion model parameters of agent homogeneity, innovation levels and near neighbour effect differ from the survey and experimental results. The final step in the research project will recalibrate the social diffusion model with agents representative of these evidence based parameters. Heterogeneous agents will reflect the four attitude segments, the proportion of innovative agents in the initial model iteration will be increased from a previously assumed 5% to the observed 31% and the agents will be modelled according to the derived function of near neighbour effect.

6. REFERENCES

Ajzen, I. (1991), The theory of planned behaviour. Organisational, *Behaviour and Human Decision Processes*, 50, 179-211.

Anselin, L. (1995), Local indicators of spatial autocorrelation, *Geographical Analysis*, 27, 93-115.

Bryan, B.A. and N.D. Crossman (in press), Systematic regional planning for multiple objective natural resource management. *Journal of Environmental Management*.

Bryan, B.A., N.D. Crossman, D. King, et al. (2007), *Lower Murray Landscape Futures Dryland Component: Volume 3 – Preliminary Analysis and Modelling*. CSIRO Water for a Healthy Country.

Cary, J., T. Webb and N. Barr (2002), *Understanding Landholders' Capacity to Change to Sustainable Practices. Insights about Practice Adoption and Social Capacity for Change*, Bureau of Rural Sciences, Canberra.

Curtis, A., B. Byron and S. McDonald (2003), Integrating spatially referenced social and biophysical data to explore landholder responses to dryland salinity in Australia. *Journal of Environemtal Management*, 68, 397-407.

Gintis, H. (2000), Beyond *Homo Economicus*: evidence from experimental economics. *Ecological Economics,* 35, 311-22.

Harrington, W. (2004), Choosing Environmental Policy. Comparing Instruments and Outcomes in the United States and Europe. In Morgenstern, R.D. and Sterner, T. (eds.) *Choosing Environmental Policy.* Resources for the Future, Washington D.C.

INRM Group (2003), *Integrated Natural Resource Management Plan for the South Australian Murray-Darling Basin*. The Integrated Natural Resource Management Group for the SAMDB.

Kahneman, D. and R. Sugden (2005), Experienced utility as a standard of policy evaluation. *Environmental and Resource Economics*, 32, 161-81.

Kahneman, D. (2003), Maps of bounded rationality: psychology for behavioural economics. *American Economic Review*, 93, 923-51.

Ligtenberg, A., A.K. Bregt and R. van Lammeren (2001), Multi-actor-based land use modelling: spatial planning using agents. *Landscape and Urban Planning,* 56, 21-33.

Pannell, D., G. Marshall, N. Barr, A. Curtis, F. Vanclay and R. Wilkinson (2006), Understanding and promoting adoption of conservation projects by rural landholders, *Australian Journal of Experimental Agriculture*, 46, 1407-24.

Parker, D.C., T. Berger and S.M. Manson, S.M (2002), Agent-based models of land-use and land-cover change. *Report and review of international workshop* October 4-7, 2001, Irvine, California, LUCC.

Stavins, R. (2003) Market based instrument policies: what can we learn from U.S. experience (and related research). Donald Bren School of Environmental Science and Management, University of California, Santa Barbara. August 23-24, 2003.

Thomson, D. (2005), Chapter 3, In: Connor, J. and Ward, J., Thomson, D. Clifton, C. *Design and Implementation of a Landholder Agreement for Recharge Credit Trade in the Upper Bet Bet Creek Catchment, Victoria.*, CSIRO, Adelaide.

Tietenburg, T. and Johnstone, N. (2004) *Ex post evaluation of tradeable permits: methodological issues and literature review; in Tradeable Permits: Policy evaluation, design and reform*. OECD, Paris.

Vanclay, F (2004), Social principles for agricultural extension to assist in the promotion of natural resource management, *Australian Journal of Experimental Agriculture*, 44, 213-22.

Ward, J., B.A. Bryan, G. Gale and T. Hobbs (2005), *Market-Based Instrument approaches to implementing priority revegetation in the South Australian Murray-Darling Basin*. CSIRO, Adelaide.