The importance of farmer behaviour: an application of Desktop MAS, a multi-agent system model for rural New Zealand communities

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Abstract

This paper describes a multi-agent system (MAS) model, Desktop MAS, designed for New Zealand's pastoral industries. Desktop MAS models the strategic decisions and behaviours of individual farmers in response to changes in their operating environment. Farmer responses determine production, economic and environmental outcomes. Each farmer has a profit-maximising or cost-minimising objective that governs their decision-making, and a social network with whom they interact. Information transfer between farmers occurs through this social network.

We consider a simple scenario analysis that investigates the impact of emissions prices on industry mix and farming intensity. We then investigate the importance of farmer behaviours and interaction.

We find that farmer social networks and objectives impact particularly on farming intensity decisions within land-use industries. Land-use change between industries becomes more sensitive to farmer attitudes as the profitability differential between land-uses narrows.

Introduction

This paper describes an initial application of the Desktop multi-agent simulation (MAS) model developed as part of the Rural Futures research programme in New Zealand. The five-year programme, originally funded by the Foundation for Research, Science and Technology (FRST), is led by AgResearch. The multi-disciplinary Rural Futures programme is working to produce tools and processes to help rural businesses and communities remain viable and sustainable in the face of future pressures.

Desktop MAS is a model of New Zealand's pastoral industries, and incorporates inputs from social and physical sciences. The model describes the strategic decisions and behaviours of individual farmers in response to changes in their operating environment. Individual farmer responses determine production, economic and environmental outcomes. Desktop MAS can represent the heterogeneity that exists in farmers, their systems, their responses to interventions and environmental changes, and the resultant consequences for the industry.

Many MAS models have been developed around the world for understanding agricultural systems, such as AgriPoliS (Happe, Kellermann, & Balmann, 2006), MPMAS (Berger, Schreinemachers, & Arnold, 2007) and SYPRIA (Manson, 2005). We reviewed these models previously during the development of Desktop MAS (see Kaye Blake et al 2010) and found that the models tend to follow a similar structure. The key actors are farmers or households. Institutions are regional councils, the market and the resource management act, who guide actors' decision making. The environment defines the actors' bio-geophysical context, including elements such as climate and soil. We have adopted a similar structure for Desktop MAS.

Desktop MAS is one of the first applications of a MAS model with farmer social networks to the New Zealand agricultural sector. Applications of MAS models with social networks are typically within the field of development economics. In MPMAS, a MAS model developed in Germany and applied to Chile and Ghana (Berger et al 2007), diffusion of irrigation production technology is governed by social networks. Farmers learn about innovations through communication in their network. Once the farmer 'knows' about the innovation, the farmer can decide whether or not to adopt. In Desktop MAS, farmers consider the actions and outcomes from other farmers in their social network, and can adopt the practices that are delivering better outcomes.

Desktop MAS also differentiates farmers by their objectives. A farmer might be either a profit-maximiser or a cost-minimiser depending on their socio-demographics. Actual rates of adoption of new production technologies or land-uses are influenced by the farmer's objective and social networks.

This paper provides an initial demonstration of the model in which we describe how farmer social networks and objectives influence farmer decisions. Section 2 provides the model description. Sections 3, 4 and 5 are the scenario analyses. Section 3 describes a base case land-use analysis that investigates how farmers change land-use under emissions pricing. Farmers have a social network and an objective (profit-maximisation or cost-minimisation) that is a function of their age. In Section 4, we assume all farmers are young and more likely to be profit-maximisers, and have extended social networks. This allows us to quantify the influence of the farmer peer network and objectives on land-use change under emissions pricing. Finally, in

Section 5, we complete a sensitivity analysis by reducing the attractiveness of dairying relative to sheep/beef. This shows how the influence of farmer objectives and social networks varies as land-use change is more marginal.

The simulations are indicative only as the model is yet to be fully validated, however the research highlights the advances from incorporating behaviour at the farmer level into land-use decision analysis. Using Desktop MAS, we can quantify how the volatility of prices, heterogeneity of farms and farmers impacts land-use and production intensity decisions.

Model description

Input

Desktop MAS is a flexible multi-agent system model that can be applied to agricultural regions. To simulate a particular region, there are various data required. These are:

- Graphical Information System (GIS) data: This is actual data from a GIS database which describes the land parcels for any specific region to be used for the farms. Currently in this initial stage of Desktop MAS there is one land parcel per farm and farmer. Future model development will allow farms to have more than one land parcel and farmers to buy and sell land parcels.
- Industry mix data: This describes the initial proportion of farms in dairying, sheep and beef and forestry.
- Biophysical data: This data relates to the actual annual input costs and other factors (fertilizer, cost of supplementary feed, stocking rate etc.) and amount of annual output produced per hectare of product (milk solid, meat, wood) and other things, such as emissions, for the 9 different farm types for each of dairy and sheep and beef, and for forestry. Because the land data is based on GIS data, the biophysical data can also be specific to a farming region.
- Other financial data: This data relates to all farm types and to expense not directly related to the performance/intensity of the farm, such as cost of overheads, labour, stock, other farm expenses, depreciation, etc. There is also other financial data such as interest rates etc.
- Economic data: This is data which may vary over the period of the simulation and affects the economic outcomes of the simulation. These include prices obtained for milk solids, meat and wood, and production costs such as cost of supplementary feed and “penalty” costs such as emissions costs, water costs, and nitrate costs.
- Social data: This data describes the age profile of farmers in the region (in up to 5 age-bands), the economic drivers and behavior characteristics for each age-band. The key social data are farmer age, presence of successor to the farming business, farmer risk profile, and peer networks.

For this paper, the region modelled is Southland, New Zealand. The GIS, biophysical, and farming-system information for sheep/beef and dairy industries are all based on data, production modelling, and emissions calculations from Southland.

This information was produced mainly by other researchers in the Rural Futures programme. We model 256 farms that cover more than 50,000 hectares, but abstract from a specific area. This means the results are representative of the Southland region in general rather than a specific area within the region.

Initialisation

Initialisation develops a synthetic agent-based population of farms and farmers that is representative of the region as described by the input data. Land is assigned to farmers, and it is determined if a farmer is an owner or a manager. Owners and managers have different decision-making jurisdictions[1]. Farmers are assigned an age, offspring and a spouse based on the population demographics of the region. The risk profile of the farmer, and the economic objective of the farmer are then determined based on these socio-demographics. Their economic objective might be profit maximisation or cost minimisation.

Finally, the farmer is assigned a social network of other farmers, from whom they can 'learn'. This a Jung network which provides a simple representation of a social network built using the "Small World" algorithm (see Jin et al 2001). The size of the network can be determined by user.

Execution

The model is designed to run for time steps of one year. Because the farmers interact within the model, all decisions of all farmers must be completed for each year before the model moves on to the next year.

For every time step, the model executes pre, main and post processing. Pre-processing completes the calculation of parameters required for the main decision-making algorithm e.g. the farmer's financial position. The main processing executes the farmer decision making. Here, the farmer's social network and objective become important. Before each farmer makes a decision, they review what their peers have done over the last 3 years. Where the peers have comparable soil types, the farmer considers the peers' actions and outcomes in their own decision-making. If a peer has had better success in meeting the farmer's objective with a different land-use or production level, the farmer can learn from the peer and adopt the same production.

Once the actions of all farmers have been computed for the year, post-processing can be completed for the region, e.g. summing total dairy production.

Using the model

Desktop MAS can be used to estimate industry mix and production levels under a range of different price projections. It considers input prices (water, supplements) output prices (meat, milk, wood), and externality prices (emissions, nitrates).

Desktop MAS allows the user to set the price paths of each of these parameters via a graphical user interface (GUI). The price path is a function of three components: the base price; price trend; and price noise. The base price is the initial price that the simulation commences with. The price trend can be linear, exponential, cyclical,

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[1] Currently all farmers are both owners and managers; future development will expand this section of the model

triangular or a saw tooth. The price noise is drawn from a uniform, Gaussian or triangular distribution. The price path over time P(t) is given by:

$$P(t) = \text{Base} + \text{Trend}(t) + \text{Noise}$$

The GUI allows the user to select the parameters for each of the three components to set the price path for each parameter.

The model outputs a wide range of information. Dairy, sheep/beef and forestry production, and total emissions can be viewed as a time series over the course of the simulation. The farming intensity of sheep/beef and dairy is also shown over time, so that moves towards or away from intensification are easily identifiable. In addition, histograms of farm size, farm profits and operating expenditure, and farmer demographics are available that show how the heterogeneity of the farming systems and the region change over time.

Desktop MAS is a probabilistic model. This means that decisions are not deterministic (or 'hard-coded') but influenced by probabilities. For example, young farmers are more likely to be profit maximisers; however there is a chance that an individual young farmer might be a cost-minimiser. Running the model many times trends the results towards the average probability of each decision. The system level results are an aggregation of the individual agent results.

Land-use change under emissions pricing

Background

Desktop MAS and the Rural Futures research programme have a focus on a sustainable future for New Zealand's rural communities that are built around agriculture. The model has been specifically designed to evaluate trade-offs between social, economic and environmental outcomes, helping decision-makers design effective policy.

One of the most prominent and ambitious environmental policies currently in New Zealand is the emissions trading scheme (ETS). The ETS puts a price on the greenhouse gas emissions from the major emitters within the New Zealand economy. Energy generation has been included in the ETS since 2012; agriculture is scheduled for inclusion in 2015, however will receive assistance in the form of free allocation of emissions permits. The assistance level starts at 90 per cent of emissions, reducing annually by 1.3 per cent. Thus at a world price that remains at $25/tonne, New Zealand agriculture would face a price of $2.50 in 2015, rising to $2.83 in 2016 and $10.63 by 2040.

Base case scenario

The base-case scenario simulation uses Desktop MAS to assess how New Zealand's rural communities might change as a result of emissions pricing. We assume the price remains at $25/tonne over the course of the simulation, but add noise from a Gaussian distribution with standard deviation of 10 per cent of the price. Agriculture receives 90 per cent assistance in the first year that reduces by 1.3 per cent each year in line with the current ETS.

Meat and milk solids prices are difficult to project. Meat prices remained flat over the decade to 2010 before rising sharply in 2011 and 2012. The milk solids long run trend is a steady increase, with recent high growth peaks. We assume the current price relativities remain, however add noise from a Gaussian distribution with a standard deviation of 10 per cent of the initial prices for both commodities.

Results

We report the land-use mix between dairy, sheep/beef and forestry; the farming intensity mix for dairy farms; and regional emissions and profit as an index (year 1 = 1000). In the emissions and profit results, we provide standard deviations to highlight the range of results possible. Variation in results occurs because we incorporate noise in the emissions, meat and milk prices. The noise is drawn from distributions during each simulation. Variation also occurs because of the probabilistic nature of farmer decision-making within the model: a farmer might be likely to adopt a new enterprise, but in any one simulation may not adopt.

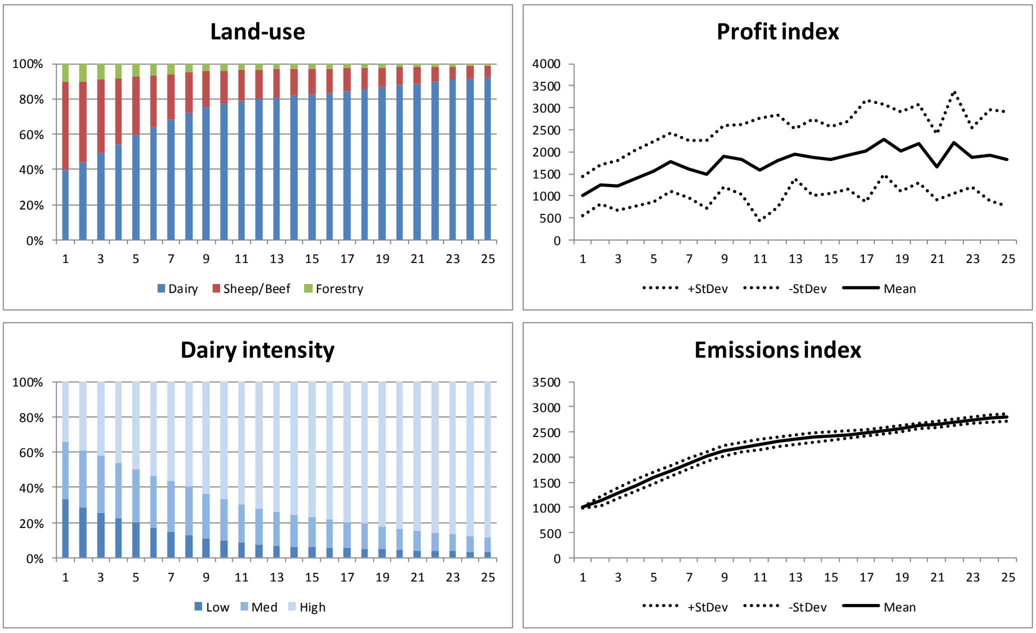
In Figure 1, the land-use mix chart in the upper left quadrant shows that the price on emissions that farmers face through the ETS is insufficient to reduce dairying, which over the 25 year simulation rises from 40 per cent of farms to 92 per cent of farms. Dairying intensity is shown in the lower left quadrant. Almost 90 per cent of dairy farms move towards high intensity dairying.

Total regional profit is shown in the upper right quadrant. It grows at 2.6 per cent per annum. Volatility in the output prices for meat and milk solids leads to a fluctuating profit index with large standard deviations. This is a realistic representation of the agricultural sector, and Desktop MAS allows us to project a range that profitability growth will most likely fall within.

Emissions are shown in the bottom right quadrant. They grow at 4.4 per cent per annum as dairying expands. Emissions projections are significantly less volatile than profits as shown by the tight confidence intervals. This suggests that output price volatility does not translate to emissions volatility. This is because emissions are a function of land-use decisions which are typically unresponsive to short term price volatility.

Figure 1: Land-use under an emissions price: base case ETS example

Indexes use 1000 at year 1.



Social network and objectives

Background

There is no such thing as the average farmer. It follows that there is also no such thing as the average farmer decision. Farmers have different acreage, soil types, cash constraints, on and off-farm labour, and management capability. In addition to these physical and economic attributes, farmer social networks, objectives and attitudes are also heterogeneous. Fairweather et al (2007) completed a farmer attitude survey for New Zealand. They found:

- forty-five per cent had a child or children living in their household
- one-third of farmers had off-farm work
- typically farmer makes key decisions but 19 per cent had a manager making key decisions
- sheep/beef is less profitable than dairy but transitions away from all types of farming to other occupations are very low
- overwhelming response to low profitability is to increase economic viability through increasing off-farm income (rather than move off the farm)
- six per cent of dairy farmers expected to have significant income from new on-farm activities.

Networks scenario

The networks scenario uses Desktop MAS to estimate the impact of heterogeneity in farmer networks and objectives. We run the same base case ETS scenario as described earlier, however we assume all farmers are young and therefore are more likely to be profit-maximisers, and have wider comparable social networks. This means the farmers will be more likely to adopt new practices and change enterprise.

Results

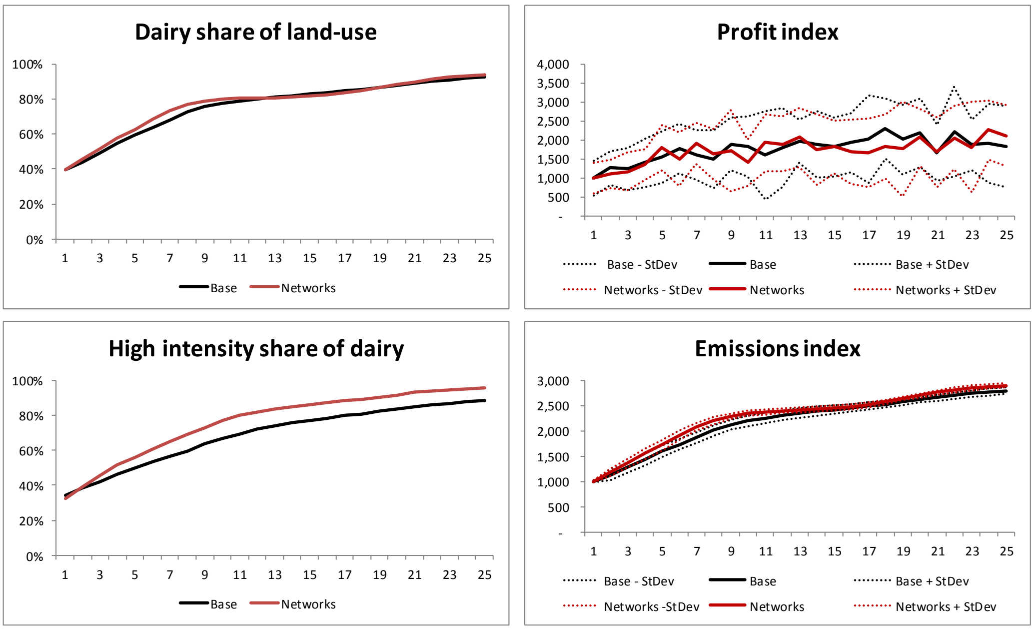
Results are shown in Figure 2. Farmer networks and objective make a small impact on the switching of land-use to dairy (see the ‘Dairy share of land-use’ graph in the upper left quadrant of Figure 2). This suggests that most switching already occurs in the base case, and that in this simulation at least, social networks and a cost-minimisation objective do not restrict land-use change.

The impact of farmer networks and objective is more pronounced on the adoption of high intensity dairying (see the ‘High intensity share of dairying graph in the bottom left quadrant). After 10 years of the simulation, 77 per cent of farmers have adopted high intensity dairying, compared to 66 per cent under the base case. This has an impact on emissions which under the networks scenario are 6 per cent higher than the base case after 10 years (see the ‘Emissions index’ graph in the bottom right quadrant).

Conversely, the impact of networks on regional profitability is not obvious because of the volatility of results (see the ‘Profit index’ graph in the upper right quadrant).

Figure 2: Impact of networks: base case

Indexes use 1000 at year 1.



Exploratory sensitivity analysis

Background

The base case ETS scenario projects a quick transition to dairying, however historically land-use change has moved at a much slower pace. Kerr and Olssen (2012) note the gradual nature of land-use change in New Zealand: sheep/beef land-use share has reduced by only 15 percentage points over the last 30 years, from about 75 per cent to 60.

The Desktop MAS incorporates some non-economic elements. However, the core of the farmer's land-use decisions is still economic profit. Given that the model simulates larger land-use changes than have actually occurred, there are two potential conclusions. First, it is likely that there is some inertia or friction that the Desktop MAS model is not yet capturing. The model does incorporate an inertia parameter on farmer decisions, but this parameter remains to be properly calibrated. Secondly, the divergence between the model and actual land-use change suggests the importance of non-economic factors in farm decisions. That is, economic profit is not an overriding consideration. Further work remains to be done on model validation.

Without this calibration and validation work, it is important to analyse the model's sensitivity to inputs. This section reports the finding of sensitivity analysis.

Sensitivity scenario

The sensitivity scenario re-runs our initial analysis under different a base case. We take the both the ETS and Networks scenarios as described earlier, but adjust the relative prices between meat and milk solids. We reduce the difference between meat and milk prices, to reduce the switching to dairy in the base case. The sheep/beef industry is now more attractive than in the base case. As a result, farms switch into the dairy industry at a lower rate.

This scenario allows better exploration of the impact of farmer networks on land-use change. We hypothesise that by reducing the economic drivers for switching into dairy, this scenario will increase the impact of non-economic factors, such as farmer networks.

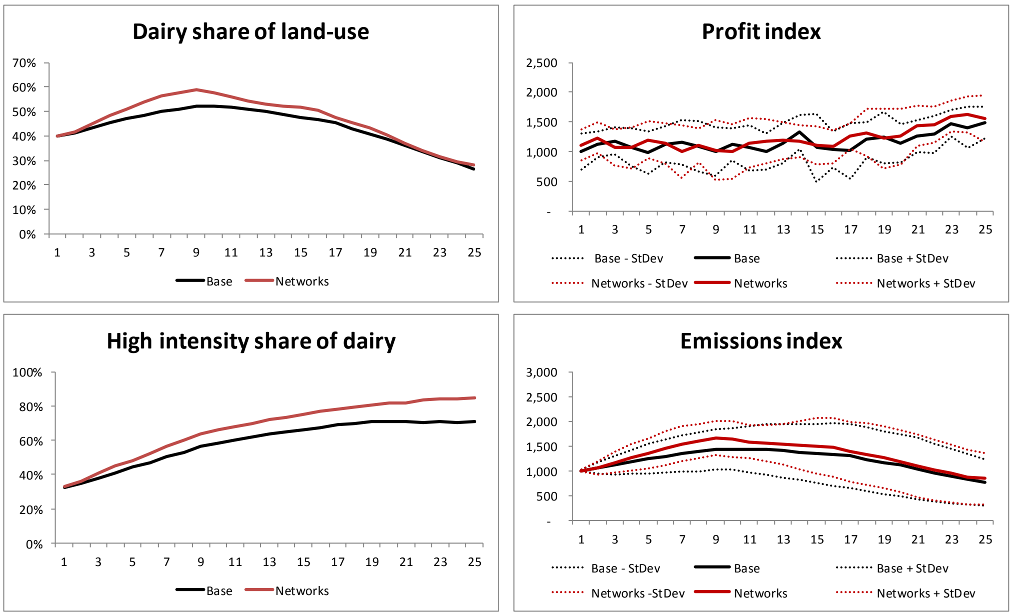
Results

Results are shown in Figure 3. We find that farmer networks and objective make an impact on land-use change, increasing dairy's share of land-use by 6 percentage points in year 10 of the simulation (see the 'Dairy share of land-use' graph in the top left quadrant of Figure 3). This is at odds with our base case results and suggests that where the economics of sheep/beef are more comparable with dairy, farmer behaviours will play a larger role in determining land-use change.

The impact of farmer networks and objective on the adoption of high intensity dairying remains significant in the sensitivity scenario (see the 'High intensity share of dairy' graph in the bottom left quadrant). This is the same outcome we found in the base case results.

Figure 3 Impact of networks: sensitivity

Indexes use 1000 at time step 1.



Discussion and conclusion

Desktop MAS is an application of MAS modelling to the New Zealand agricultural sector. It allows researchers to include farmer heterogeneity and complex interactions between social networks when analysing policy. The results in this initial report are indicative only, however they provide a number of important insights into the response of rural communities. First, emissions pricing will impact land-use, however these impacts are not straight-forward. An agent based approach allows complex system and behavioural responses to be considered. Second, farmer social networks and objective significantly impact the rate of adoption of different farming systems. Land-use change may also be impacted by differences in farmer objectives depending on the underlying economics of the respective land-uses. Where one land-use is clearly more profitable, the land-use decision is less sensitive to farmer behaviour; conversely when the profitability differential between land-use options is smaller, heterogeneous farmer attitudes will result in divergent land-use decisions. Third, volatility of output prices leads to uncertain profit projections that can outweigh other factors. Fourth, emissions projections are likely to be less uncertain than profit projections, as emissions are a function of land-use change which is not as volatile as output prices.

There are advancements and revisions to the model that are planned over the coming months to continue to improve our representation of farmer decision-making. First, we are hoping to validate the model using data from Southland and historical price trends. We also plan to use other regional data from New Zealand and increase the number of agricultural industries modelled.

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