This paper describes the process and results of validating a simulation model of agriculture for a region in New Zealand. Validation is treated as a process, in which simulation models are made useful for specific purposes by making them conform to observed historical trends and relationships. In this case, the model was calibrated to reproduce the year-by-year conversion to dairying from 1993 to 2012 in Southland, New Zealand. This was achieved by holding constant some elements of the simulation model, based on economic theory or data, and by running simulations on a range of values for two key parameters. The results of the model were then compared, and it demonstrated that empirical validation is possible if approached pragmatically with a view to the intended use of the model. Important elements are: using stylised facts to limit the parameter space; establishing the range of model outcomes and focusing on the most likely parameter space; focusing the search for parameter values where there is the greatest uncertainty; and using historical data to calibrate models.

Keywords:
Agriculture, Interdisciplinary Research, Multi-Agent Simulation, Validation, Agent-Based Model

Introduction

1.1 Charles Macal presented the keynote address to the 14th International Workshop on Multi-Agent Based Simulation on 7 May 2013. He noted that one of the first questions any person who is presenting a model or its validation will be asked is, “Has your model been validated?” Macal suggested that without the ability to say “yes,” the model is unlikely to be adopted or used in practice. This situation raises several questions: what does “validated” actually mean in practice, can it be achieved and if so, how?

1.2 Some economists claim that meaningful validation is impossible (Windrum et al. 2007): Socio-economic systems, it is argued, are inherently open-ended, interdependent and subject to structural change. How can one then hope to effectively isolate a specific “sphere of reality,” specify all relations between phenomena within that sphere and the external environment, and build a model describing all important phenomena observed within the sphere (together with all essential influences of the external environment)?

This viewpoint suggests that, because there are uncertainties and complexities, model validation is impossible. An alternative viewpoint argues instead that validation for social science modelling is shades of grey rather than black or white. Models of human behaviour are not precluded from “validation”, but the validation is an on-going process in building trust in the model and its ability to provide insights into the research questions at hand. Macal (2013) expressed this view succinctly:

“The goal of model validation is to make the model useful in the sense that the model addresses the right problem, provides accurate information about the system being modelled, and helps to [ensure] the model is actually used.”

It is perhaps unsurprising then that the literature suggests a wide range of validation approaches, but as Fagiolo et al. (2006, p. 9) stated, “There is no consensus at all about how (and if) AB [agent-based] models should be empirically validated.” The intent and process of validation is thus a contested area of research.

1.3 This paper provides an example of model validation. The main validation exercise was to compare actual past land-use change to land-use change produced by the model, similar to Bell (2011). Land-use and land-use change is a key driver of both rural economies and environment impacts of agriculture. For agricultural modelling generally and the present research in particular, modelling land-use is a useful purpose as defined by Galan et al. (2009) and sets the scope for the validation. To set the stage for the validation exercise, this paper reviews the literature on validation to uncover themes within the processes and approaches that have been adopted. The paper then describes how a multi-agent simulation (MAS) developed for modelling the Southland region of New Zealand was empirically validated, and draws some lessons about validation from that exercise.

Literature review

2.1 Validation is not a single thing, a unified concept or an agreed process. Instead, there are several processes targeting similar concepts, all working towards demonstrating that a model is useful for describing observed phenomena. This review describes different types or modes of validation: scope of validation, verification, theoretical validation, empirical validation, statistical validation and participatory validation.

2.2 A key issue is the scope of validation. A common theme is that validation is inextricably linked to the model’s purpose or research question. Galan et al. (2009) noted, “For us, validation is the process of assessing how useful a model is for a certain purpose.” The key phrase here is “for a certain purpose”. Their validation aimed to show that a model is useful for a particular scope of questions. Targeting the validation to the outputs that matter for the research question is emphasised by Berger et al. (2010) and Macal (2013). The validation plan for any model therefore needs to be designed with the model’s purpose in mind. Thus, model validity is contingent: a model is not universally valid, but valid for specific uses in specific contexts. The questions, “has your model been validated?”, is incomplete unless it specifies the context. Importantly, there is concern over whether “validation” is even a useful term, as it appears to mean different things to different people (Augustais et al. 2014).

2.3 A second theme in the literature is verification, which answers the question “is the simulation working as you want it to do?” Galan et al. (2009) suggested verification is the process of looking for errors, where errors appear when a model does not comply with the specifications imposed by its own developer. Some, such as Marks (2013), suggest verification is separate from validation, and that the two combine to produce assurance. Verification goes by other names such as program validation (Richard et al. 2006) and internal validity (Bharathy & Silverman 2010). These terms point to the same aim: to ensure the model is accurately representing what the authors want it to. Some ways of achieving verification are testing and debugging model code, re-implementing code in different programming languages or on different computers, applying the model to very well understood examples, and creating extractions of the model (Galan et al. 2009). These examples emphasise that verification is procedural. It is demonstrated by following a processes and having a successful or satisfactory outcome.

2.4 Theoretical validation is a third theme widely discussed within this literature. Theoretical validation seeks to ensure the correct application of relevant theories within the model. Richard et al. (2006) described theory validity as the validity of the theory relative to the simuland (the real-world system). Schreinemachers and Berger (2011) note that one part of validation, which they refer to as “validation by construct” (based on McCull and Aparid 1986), is ensuring that the relationships within the model are based on sound theory. Macal (2013) comments that one component of validation is validating theory, which he defines as ensuring the technical relationships within the model are appropriately grounded. In a social science application, the relevant theories may touch on technology adoption behaviours, social networks, objective functions, production and expenditure functions. In agriculture, physical science theories may also be included, such as theories about the relationship of soil types to pasture productivity and environmental impacts.

2.5 Probably the largest theme is empirical validation. Fagiolo et al. (2006) provided three widely cited approaches for empirical validation: indirect calibration, the Werker-Brenner approach and the history-friendly approach. The steps involved for each of these approaches are directly taken from Moss (2009). In the indirect calibration approach, researchers identify macro-level "stylised facts" such as firm-size distributions or employment-growth relations. They then inform model design by "empirical and experimental evidence about microeconomic behaviour and interactions." The stylised facts are then used to provide ex ante restrictions on the parameter space for the microeconomic functions, possibly by using Monte Carlo techniques. Indirect calibration identifies model parameters based on several sources of information – macro-level regularities plus available microeconomic estimates. In the Werker-Brenner approach, researchers use existing empirical knowledge to calibrate initial conditions and the ranges of model parameters. They then obtain simulation outputs for each set of parameter values for the model. From these outputs, they discard all sets of parameter values except those that "are associated to the highest likelihood by the current known facts [i.e. empirical realisations]." The surviving parameter sets together with domain expertise from "historians" are used to further constrain the parameter space of the model. The Werker-Brenner approach is similar to indirect calibration that it combines different ways of knowing – empirically determined relationships plus domain expertise – but inverts the process to focus on the empirical data first and the "empiricist" or "stylised facts" second. The history-friendly approach starts by designing the agents and interaction mechanisms on the basis of detailed empirical studies, anecdotal evidence and historical studies. These data are then used to assist "the identification of initial conditions and parameters on key variables likely to generate the observed history." Researchers then compare the model outputs (the "simulated historical process") to the observed history of the domain being studied. The history-friendly approach thus uses both micro-level and macro-level data, moving from the former to the latter.

2.6 Although there may be theoretical appeal in differentiating the three approaches, they do not seem to have been explicitly used in much of the practical validation literature. Villon et al. (2012), who adopted the indirect calibration method in validating a land-use change model, is an obvious exception. While the order of application changes between approaches, the consistent message is to use empirical evidence, anecdotal evidence, stylised facts, and actual historical outcomes to limit the set of values for unknown parameters. They are essentially structured programmes for working towards convergent validity. Macal (2013) did suggest that validation can make use of critical cases or historical examples that can be used as natural experiments, but does not explicitly link the use of such examples to any specific validation approach as described by Fagiolo et al. (2006).
4.1 from 220 hectares to almost 300 hectares, or 36%. The predominant land use in Southland, both in 1993 and now, is mixed sheep and beef farming. Over that time, dairying has become a more important land use. In 1993, less than 2% of land was used for dairy farming. Since then, dairying has grown strongly, and now accounts for between 15 and 20% of agricultural and forestry land-use within Southland. Forestry has also grown, but at a slower rate than dairy, from 4% of land-use in 1993 to 7% in 2012. The trends are shown in Figure 2.

Appendix B. Class diagrams for key parts of the model are contained in Appendix C.

A model run follows a series of steps, which are described below and shown as flowcharts in Appendix A.

- Initialization: Farms and farmers are loaded into the model. Farms are read into the model from datasets based on Agribase (AsuraQuality New Zealand, several years) and the Land Resource Inventory and Land Cover Database (2012). Farmers are generated from distributions of farmer demographics based on Agribase. Farms and farmers are assigned to each other on a one-for-one basis. Farmers are also assigned to peer networks built using the "Small World" algorithm (Jin et al. 2001), which is a mathematical representation of connectedness and clustering effects seen in social networks.

- Pre-processing: Farmers are aged by one year. Age affects several aspects of farmer behavior: First, farmers above a certain age are likely to have children although not all do; this is assigned probabilistically. Secondly, age has an effect on the farmer's objective for farming. The model allows farmer-agents to have one of three objectives, high-change profit maximisation, low-change profit maximisation or cost minimisation. Profit maximisation produces farm decisions focused on financial returns, and with some farmers more likely to change land use than others. Cost minimisation mimics a defensive or satisfying farming strategy. Older farmers are more likely to be cost minimisers, while younger farmers and farmers with successors are more likely to follow a profit maximising strategy. The pre-processing stage checks farmers' ages and changes these parameters if appropriate.

- Main processing: Farmers make their decisions about land use for their farms. Farmers review the feasible options. The feasible options are generated with a combination of exogenous production data, based on farm systems modelling using Aqsim and Farmax, and price data within RF-MAS. Aqsim is simulation software that uses biophysical data to estimate pasture production. Farmax is a decision support tool that allows pastoral farmers to plan production, using pasture growth rates and off-farm inputs to estimate production. Each farmer decides probabilistically whether to change land use, and then selects the land use that best meets the economic objective.

- Post-processing: the model calculates output values for each farm, such as quantity of production, value of production, profit, nitrogen and phosphorus losses and greenhouse gas emissions. It also updates prices, and then retires farmers and generates successors if required. The model then returns to the pre-processing phase, which will lead either to a new time step or termination of the modelling.

Data

The main validation exercise focused on land-use change, so these data are central to the modelling and validation. The total amount of hectares used in agricultural and forestry production in Southland has slowly decreased from 1.2 million hectares in 1993 to 1.1 million hectares today. Over the same period, the number of farms has dropped by 32% from 5,379 to 3,660, while the average farm size has increased from 220 hectares to almost 300 hectares, or 36%. The predominant land use in Southland, both in 1993 and now, is mixed sheep and beef farming. Over that time, dairying has become a more important land use. In 1993, less than 2% of land was used for dairy farming. Since then, dairying has grown strongly, and now accounts for between 15 and 20% of agricultural and forestry land-use within Southland. Forestry has also grown, but at a slower rate than dairy, from 4% of land-use in 1993 to 7% in 2012. The trends are shown in Figure 2.
4.2 To understand historical production trends, data on dairy farming operating revenue and expenditure were sourced from Dairy New Zealand, the country’s main dairy industry group. Expenditure per hectare, income per hectare and prices remained relatively flat throughout the 1990s. Expenditure per hectare was 40% of current levels, prices were about half. The production per hectare index exhibits a more constant growth trend over the last 20 years. Income per hectare was about 60% of the current level. These trends are shown in Figure 3. The figure presents indices for expenses per hectare, income per hectare, production per hectare and prices, with the 2012 value set to 1.00.

4.3 Sheep and beef farming has had relatively flat returns over this period, as shown in Figure 4. In 1993, expenses per hectare and income per hectare were both about 60% of today’s values. Prices were less than 45% of today. Production per hectare has remained fairly constant.

4.4 An interesting comparison is the profitability of dairy versus sheep and beef, as shown in Figure 5. Sheep and beef profitability has increased slowly over time; dairy profitability has been more volatile, but significantly greater than sheep and beef at all times over the 20 year period. This is important when considering farmer decision-making. In every period, farmers concerned with maximising profits would compare sheep and beef farming to dairy farming and conclude that the latter was more profitable. A model of land-use change in Southland that relied solely on such economic calculations would tend to produce quick and significant land-use change. However, the fact that the actual trend has been a slow rate of conversion suggests that profit maximisation is not the sole driver of land use in Southland. For this reason, an agent-based model with decision rules other than profit maximisation was considered appropriate.
5.5 RF-MAS was table to replicate the growth in dairying. It was particularly accurate for the later years of the comparison as the share of dairying grew.

The result of the analysis is shown in Figure 7, which compares the share of dairying in Southland in RF-MAS in each time-step versus the actual growth in dairying over the last 20 years. The figure indicates that RF-MAS was able to replicate the growth in dairying. It was particularly accurate for the later years of the comparison as the share of dairying grew.

Table 1: Parameters affecting land use decisions

| % peers | The higher the % of peers, the larger the peer group and the more likely a farmer was to observe a better farming outcome. Farmers must observe a better farming practice before they can adopt it. Higher % peers led to higher probability of change. |
|---------|--------------------------------------------------------------------------------------------------|
| Comparison factor | This factor described how much weight farmers put on information about the performance of different land uses. If weightings were all 1, then there was no weighting difference between intensities – farmers did not discount information they received from other land uses. If weightings were >1, then the parameter reduced the likelihood of change (like risk aversion). Higher weightings led to higher probability of change. |
| Median-time-to-change (inertia) | This median was a simple inertia parameter that reduced flip-flopping between land-uses. The higher the median-time-to-change, the lower the probability of change in any given year. |
| Maximum change | This parameter provided the upper asymptote for the probability of change. A higher a increased the probability of change. |
| Minimum spike | The probability of change was related to levels but also to changes in levels, similar to the concept of a "just noticeable difference" (Gigerenzer & Selten 2001). This parameter was used to induce above-average land-use change. The higher this parameter, the less often a price increase is treated as a price spike leading to greater change. |
| Impact spike | This parameter adjusted the impact of a price spike on the probability of land-use change. The higher this parameter, the higher the probability of conversion when price spikes occur. |

5.2 The bio-physical and economic rules were reasonably straight-forward and were validated by their theoretical strength (Berger et al. 2010). For example, dairying in Southland is on the whole confined to Land Use Capability classes 2 through 4. It is more difficult to run dairying operations easily and profitability on the higher numbered land classes, which have greater slopes and/or poorer-quality soils. Similarly, farm budgets are well understood: the profitability of dairying versus sheep and beef was based on Farmax modelling results, but was also supported by production budgets from the Ministry for Primary Industries and in Pangborn (2010). The comparison weighting factor was fixed at 0.75 and not changed for the calibration; the parameter is not used for the calibration exercise, but is available for future scenario development.

5.3 The median-time-to-change parameter was set at seven years. When used in the sigmoid probability of change equation (see Appendix B),

$$C = a - \frac{a}{1 + \exp(-\text{median} \times \text{price} \times \text{time} \times \text{average})}$$

where $C$ is the probability of change, $a$ is the maximum change, $t$ is the time since last change and $\text{median}$ is the median time to change. The parameter produces a low probability of change in the first few years and a steeply rising probability in the next few years. If reach 95% of the maximum change probability a in year 10. Because the rate of conversion increased and decreased over time, a step was added to the basic decision algorithm (described in Appendix B). If prices in an industry spiked above a certain growth rate, the likelihood the farmer changing to that land use was increased. In mathematical terms, the algorithm was as follows:

If $p_t \times \text{price} \text{in year } t$ then

$$C = C \times (1 + \text{impact spike})$$

where $p_t = \text{commodity price in year } t$

minimum spike = the price spike required to induce the additional behavioural response

impact spike = the impact of the price spike on the probability of land-use change.

These two parameters were estimated by analysing the historical data on the impact of price spikes on the rates of conversion, which is an appropriate validation technique (Fagiolo et al. 2006; Macal 2013).

5.4 Less well understood were the two remaining parameters linked to land-use decisions. First, the impact of the size of peer networks was not understood. The size of peer networks for Southland farmers was not known. Secondly, the willingness of farmers to change land use and behavioural responses to information was not known. Burton (2006; 2009) has argued that farmers move between stages (or "typologies") over the life-course: risk-taking and profit-maximising in their early years of farming before typically becoming more risk-averse and cost-minimising as they near retirement. However, the link between these dynamics and actual farmer behaviour with respect to land-use change has not been readily quantified. The goal of the validation exercise was therefore to calibrate the maximum probability of change and percentage of peers parameters.

5.5 The analysis used a step-wise process to select likely values for the two parameters. First, the model was run using a range of values for the two variables. The results in the final year (2012) were compared with the actual share of dairying in Southland (16.4% of land area). Parameters that led to model results between 16% and 20% were retained for further inspection. Secondly, the year-by-year model results were compared against annual data for actual dairying area. Standard deviations were calculated by conducting 20 simulations for each set of parameters. The fit of the actual area to the averages and standard deviations was assessed visually, and likely central values for the two parameters were selected. Finally, sensitivity tests for the two parameters were conducted to confirm the selection of central estimates.

Results

Calibrating to land-use change

6.1 The result of the analysis is shown in Figure 7, which compares the share of dairying in Southland in RF-MAS in each time-step versus the actual growth in dairying over the last 20 years. The figure indicates that RF-MAS was able to replicate the growth in dairying. It was particularly accurate for the later years of the comparison as the share of dairying grew.
6.2 The result in Figure 7 is based on final calibrated values for the two studied parameters shown in Table 2. The percentage of peers was specified as a percentage of the total number of farmers in the geographic area being analysed. In this case it suggested each farmer had around 35 peers. The maximum change, which provided a maximum probability of a farm changing land use, was set at 3%. The goodness of fit can be calculated by comparing actual annual data to modelled data using a similar calculation to the coefficient of determination ($R^2$) for regression models (Kennedy 2003, p. 29):

$$R^2 = 1 - \frac{\text{error sum of squares}}{\text{total sum of squares}}.$$  

6.3 The goodness of fit of the simulation can similarly be estimated by dividing the error sum of squares from the model by the total sum of squares. The numerator is the sum over the period of the squared difference between the actual area and the modelled area. The denominator is the sum of the squared difference between the actual value for each year and the average for the period. For the parameter values in Table 2, the goodness of fit was 0.884.

| Parameter | Value |
|-----------|-------|
| % peers   | 3%    |
| Maximum change | 3%   |

6.4 The results for the two parameters were also subjected to sensitivity analysis to determine the impacts of the various decision parameters on final results.

Sensitivity test 1: Percentage of peers

6.5 The first sensitivity test compared the baseline of 3% peers to results from 2.5% and 3.5% peers. Figure 8 shows that changing the % peers parameter by 0.5% moved the results by about one standard deviation. It also suggests that the standard deviation increased as the % peers was reduced, indicating increased uncertainty around model results as the peer groups are restricted. In RF-MAS, information about land use is obtained from peers. With smaller peer groups, farmers have less information on alternative land uses available.

Sensitivity test 2: maximum change

6.6 In the second sensitivity test, the maximum change parameter was adjusted. The baseline was 3%, and values of 2% and 4% were also modelled. Figure 9 shows that changing the maximum change parameter by 1.0% moved the results by about one standard deviation. The standard deviation also increased as the maximum change parameter increased. Allowing for a greater possibility of change increased the uncertainty around farmers’ choices of land use.

Discussion

7.1 The research had the goal of validating a MAS model of rural Southland in New Zealand. The validation was intended to make the model useful for research on farming in Southland. The “right problem” to address (McCa 2013) was the expansion of dairying, a key element of land-use change and concern for the region. The validation therefore focused on reproducing the observed land-use change over the past 20 years.

7.2 The validation focused specifically on two themes from the literature on validation for simulation models. The first theme was scope. Following Galan et al. (2009), the research first determined the scope of the validation by defining the geographic area, time period, and target variables. The second theme was goodness of fit. The research calculated goodness of fit using the coefficient of determination ($R^2$) and compared actual annual data to modelled data. The research found a goodness of fit of 0.884 for the model, indicating a reasonable fit between actual and modelled data.
validation by identifying the important issues in Southland and validating the model around a key issue. In addition, policy makers and industry groups are interested in the process that leads to land-use change. Because changes at the farm level are the result of decisions by individual farmers, RF-MAS particularly focused on those decisions.

7.3 The second theme from the literature was empirical validation, with reference especially to Fagiolo et al. (2009) and Schreinemachers and Berger (2011). The historical experience of conversion to dairying was taken as a phenomenon to be explained. The validity of RF-MAS was partly established by building the model based on sound theory, which provided indirect calibration. In addition, several elements of RF-MAS were set by reference to other data or modelling, such as the relative profitability of dairying and sheep and beef farming. Additional modelling on the historical data also provided estimates of some parameters. It was found, for example, that conversion did not happen smoothly over time, so the relationship between spikes in the commodity price of milk solids and increases in conversion rates were used to improve the model. Finally, RF-MAS was calibrated to historical land-use change data for the region by identifying key uncertain parameters, conducting multiple simulations, and selecting parameter values that provided good fit. The goodness of fit statistic between the historical data and the model results was 0.884, and sensitivity analysis showed that different values of the calibrated parameters led to worse fit. The results showed that RF-MAS could reproduce the history of land-use change in Southland, which is taken as validation of RF-MAS for the purpose of modelling land use by linking farmer decisions to regional trends.

7.4 The research is an example of a practical application of the theory of validation, providing some commentary on the validation literature. First, it demonstrates that meaningful validation is possible, despite some critics (Windrum et al. 2007). The validation reported here demonstrates that modellers can reproduce observed phenomena with some accuracy, provided they properly establish the scope of validation and focus on key areas of uncertainty. This validation can be "meaningful" by allowing researchers and others to understand the phenomena better. Secondly, it is an example of how validation can be done using the ideas from the theory of validation. Important elements are: using stylised facts to limit the parameter space ex ante, establishing the range of model outcomes and focusing on the most likely parameter space, focusing the search for parameter values where there is the greatest uncertainty, and using historical data to calibrate models.

7.5 One limitation of the exercise is the focus on a single model. The research validated a particular model by setting some parameters through theory, estimating other parameters separately through statistical analysis, and calibrating two parameters through simulation. A different model would likely produce different results. In particular, it might provide different estimates of the size of farmer peer groups and the maximum annual likelihood of changing land uses. One possible comparison is to the slow rate of dairy conversion reported by Kerr and Olssen (2006), although they focused on land-use changes at the national scale. With more work, additional external validation of model parameters may be possible.

7.6 Development of this particular model, RF-MAS, can proceed in a few directions. One direction is scenario modelling of Southland using the existing model. The model is now a tool that researchers and community members can use to explore "what-if" questions and think about potential futures for the region. A second direction is towards greater generalizability. The model is based on data specific to Southland and calibration to historical trends in Southland. There is therefore the potential for overfitting: the model may explain the past very well without providing a good guide to the future. To examine the potential impacts of overfitting, RF-MAS can be applied to other regions of New Zealand. A third direction is towards more detail and specificity. In particular, the behaviour of farmer-agents in the model – reliance on peer community members can use to explore "what-if" questions and think about potential futures for the region. A second direction is towards greater generalizability. The model is based on data specific to Southland and calibration to historical trends in Southland. There is therefore the potential for overfitting: the model may explain the past very well without providing a good guide to the future. To examine the potential impacts of overfitting, RF-MAS can be applied to other regions of New Zealand. A third direction is towards more detail and specificity. In particular, the behaviour of farmer-agents in the model – reliance on peer community members can use to explore "what-if" questions and think about potential futures for the region. A second direction is towards greater generalizability. The model is based on data specific to Southland and calibration to historical trends in Southland. There is therefore the potential for overfitting: the model may explain the past very well without providing a good guide to the future. To examine the potential impacts of overfitting, RF-MAS can be applied to other regions of New Zealand. A third direction is towards more detail and specificity. In particular, the behaviour of farmer-agents in the model – reliance on peer

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Appendix A

8.1 RF-MAS is a file written in C# that calls data from CSV files and produces output in the same format. The process of the model is shown in a series of figures.

8.2 The first figure is the Initialisation phase. This phase obtains data about the farms and farmers to be modelled, links one farm to one farmer, and create social networks of farmers. The second theme from the literature was empirical validation, with reference especially to Fagiolo et al. (2009) and Schreinemachers and Berger (2011). The historical experience of conversion to dairying was taken as a phenomenon to be explained. The validity of RF-MAS was partly established by building the model based on sound theory, which provided indirect calibration. In addition, several elements of RF-MAS were set by reference to other data or modelling, such as the relative profitability of dairying and sheep and beef farming. Additional modelling on the historical data also provided estimates of some parameters. It was found, for example, that conversion did not happen smoothly over time, so the relationship between spikes in the commodity price of milk solids and increases in conversion rates were used to improve the model. Finally, RF-MAS was calibrated to historical land-use change data for the region by identifying key uncertain parameters, conducting multiple simulations, and selecting parameter values that provided good fit. The goodness of fit statistic between the historical data and the model results was 0.884, and sensitivity analysis showed that different values of the calibrated parameters led to worse fit. The results showed that RF-MAS could reproduce the history of land-use change in Southland, which is taken as validation of RF-MAS for the purpose of modelling land use by linking farmer decisions to regional trends.

8.3 The next three figures concern each time-step of the model. Each time-step has three phases: Pre-processing, Main processing, and Post-processing. The Pre-processing phase is focused on ageing farmers by one year and updating any related information, such as their economic objective and risk behaviour. In the Main processing phase, farmers make a choice about the land use on their farms. They do this by determining whether to change their land use, and then selecting the land use that best meets their objectives. The Post-processing phase updates the farm accounts, calculates economic performance, calculates nutrient losses, and handles farmer retirement. The model then returns to the Pre-processing phase and goes through the next time step or terminates.
Figure A1. RF-MAS Initialisation phase

1. Click Run button
2. Any more time steps to process?
   - No → End Simulation
   - Yes →
3. Are prices from data generated?
   - Yes → Data Generated
   - No →
4. Read price data
5. Generate prices from distributions
6. Set prices in Costing Model
7. Any more farmers?
   - No
   - Yes → Go to next farmer
8. Age farmer by one year
9. Is farmer old enough for children?
   - Yes → Does farmer have children?
     - Yes → Assign children based on probability
     - No →
   - No →
10. Has farmer aged into next age band?
    - Yes → Update behaviour and economic objective profiles
    - No →
11. Main Processing phase
Figure A2. RF-MAS Pre-processing phase

Any more farmers?

Yes

Go to next farmer

Calculate performance of feasible land uses

Select best land use according to farmer’s objective

Calculate probability of change

Is probability above threshold?

No

Post-processing phase

No

Obtain feasible land uses for farm

Yes

Change land use for farm

Figure A3. RF-MAS Main processing phase
Adaptation

Land/farms

Agents

their age and presence of a successor) and a median-time-to-change parameter, in a function that creates a sigmoid curve. The probability of change is calculated by following function.
Appendix C

This appendix contains class diagrams for key elements of RF-MAS. Note that RF-MAS is a continuing project, so that the class diagrams contain elements that are not currently used.
Figure C2. FarmData class diagram for RF-MAS
Figure C3. Farmer-Agent class diagram for RF-MAS
Figure C4. FarmFinancials diagram for RF-MAS

Figure C5. Simulation class diagram for RF-MAS
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