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1 Introduction

Validation has been a major topic for the CAVES Project in the reporting period. All three case studies have undertaken steps to validate the developed models with respective stakeholders. The particular focus has been on qualitative aspects of model processes, such as decision-making and social approval. For the South Africa case study, this has included a joint field trip to Sekhukhune District, Limpopo Province by both the case study and the modelling team. In the Odra case study, a role-playing computer game has been developed. The Grampian case study has applied interviews with farmers and key informants, chosen to reflect different perspectives.

Experiences and findings from the above work have found their way into a draft of Deliverable 10, the working paper on case study validation. It introduces validation actions planned in the CAVES project such as methodology, approaches and protocols. If this draft is accepted at the project meeting in Kassel, this will be used as a template to document the validation activities of the three case studies.

In addition to validation, considerable progress has been made on the different models and the analysis of the resulting social networks. A range of scientific papers originating from the successful research undertaken in the CAVES project in the reporting period documents the diverse achievements in this area.

2 Modelling issues

The following sections report on the work undertaken by the different modelling teams during the fifth six months of the CAVES project.

2.1 Centre for Policy Modelling

In April, the CPM team took part in a field trip to the Sekhukhune District in collaboration with the case study team from SEI Oxford (cf. section 3.1.1). After this, work has concentrated on further developing the declarative model for the South African case study. This included not only the integration of insights gained on the field trip but also devising effective techniques of using Jess with Java. Other foci of work have been researching measures for dynamical network analysis and continuing the development of the procedural model. In addition, several academic papers have been written and submitted to international conferences.

2.1.1 Fieldtrip

For the CPM modelling team the fieldtrip to South Africa provided an important opportunity to test assumptions built into the models. Thus; the validation process could incorporate stakeholder interaction at an early enough stage to allow for valuable feedback to inform the model development. In our case, the stakeholder interaction resulted in a revision of endorsements and elicited knowledge about friendship networks, marriage and groups.

On the second day of visiting the village of Ga-Selala we engaged in an exercise to extract empirical data about the friendship network. For this purpose the male and female adults present were interviewed separately. Everyone was asked to list up to four people with whom they most enjoy to spend time and to specify how they know each other.

While this exercise unfortunately didn’t result in a network to be used for comparison with model output in the validation process as too few people took part, it nevertheless helped to identify types of relationships (friends are relatives, neighbours, colleagues, known from school, church or savings clubs). Moreover, we discovered that people in the village do not distinguish between friends and acquaintances – so far one of the assumptions of the models. Once people are members of the same group, e.g. the child care group, they become friends. This particular information led to revising the endorsements token used in the declarative model: *is-acquaintance* was dropped (only is-friend remained) and *same-club* and *same-work* were added.

2.1.2 Declarative Model

The declarative model has been extended to incorporate further social processes like burial societies, marriages, education and the spread of HIV/AIDS.

Sexual Networks and HIV/AIDS

For the purpose of the latter, the formation of sexual networks has been introduced. These take into account that people may have several concurrent sexual partners. Since same-gender partnerships are more or less taboo in the case study area the model only considers heterosexual relationships. The resulting sexual network is therefore a two-mode network with males and females forming the two distinct sets of nodes.

Adults between 15 and 64 are considered to be sexually active. Males of this age group look for potential partners among the siblings of friends, work colleagues and the social groups they belong to. When they encounter a female adult they find attractive (same age or younger, overall endorsement value higher than a certain threshold particular to the male individual) they make a pass at her, modelled as sending her a partner request.

Females evaluate all requests received at the same time and pick the best of the ”applicants” if (i) their overall endorsement value is higher than the female’s threshold and (ii) in case they already have a certain number of current partners, if this applicant’s endorsement value is higher than the lowest endorsement value of the current partners. In this case, the current partner with the lowest endorsement value is dropped, thus ending their sexual relationship.

Relationships otherwise may end due to marriage of one of the partners or – in absence of detailed knowledge about real reasons – are broken up randomly. The probability applied is influenced by the number of current partners and the person’s age; it is highest for young people with a maximum number of concurrent partners.

The spread of HIV infection makes use of the sexual network. At initialisation of the model, a number of adults are assigned to be HIV positive. Number and age groups follow the estimated HIV prevalence distribution for males and females from the South African National HIV Survey, 2005[1]. During a simulation run the infection is spread between adults by sexual intercourse of an infected with a non-infected partner. The probability to contract HIV is modelled as the transmission rate per sexual contact with an HIV-infected person (0.03%[2]) influenced by the frequency of sexual contacts (modelled as individual tags) and a constant factor (3) for migrants to account for their higher risk.

Figure 1 shows a snapshot of the sexual network at tick 12 of one simulation run. The colours of the nodes denote gender and HIV infection: blue/purple for males and yellow/red for females.

Stokvels

The rules for stokvels have been revised. Whereas in the previous implementation only household heads tried to join a stokvel whenever there was enough money left at the end of a

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[1] http://www.avert.org/safricastats.htm

[2] http://library.med.utah.edu/WebPath/TUTORIAL/AIDS/HIV.html

month, this rule has been transferred to the behaviour regarding membership in burial societies. Stokvels do not exist in the model from the start of the simulation but are formed by group of friends whenever enough people mutually express the desire to do so. Currently, we assume the following rules to govern this behaviour:

- Single adult males with employment will try to join a stokvel to save up for *lobola*.
- Married adult males with employment still living in their parents' household will join a stokvel to save up for a house.
- Adult females will try to join a stokvel to save up for (their) childrens' education, i.e. when there are children over the age of 14 in the household.

If there are already stokvels, they will join the one most of their friends belong to. If there aren't any stokvels within their circle of friends, they will invite their friends to form a new stokvel.

The rules for payment of membership fees, requests for grace periods and eventually leaving of a group are the same for stokvels and burial societies. The only difference is that burial societies are given priority over stokvels in case there is not enough money to pay both.

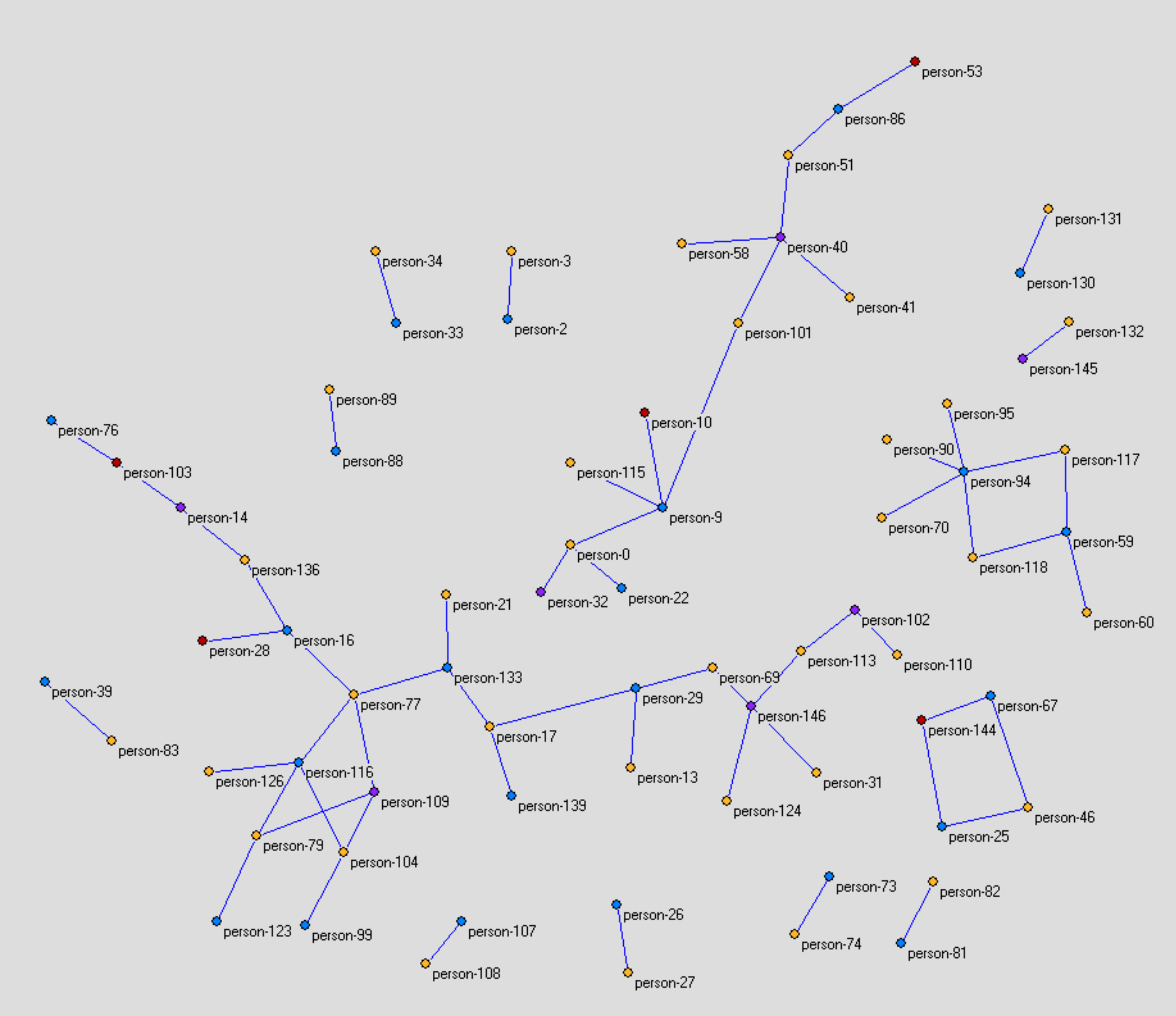

Figure 1: Snapshot of the sexual network.

2.1.3 Procedural Model

Several arbitrary assumptions in the model were replaced with more plausible assumptions following the validation exercise by our case study partners at the SEI (Oxford), prior to the CPM/SEI fieldtrip last April. Following the fieldtrip to the Sekhukhune District, several changes in the model have been introduced. Moreover, the grant values (i.e. child, foster, disability and pension grants) have been revised by the South Africa government this year. The significance of the new grant values have been studied in the model. A detailed account of the update of such assumptions and the introduction of the new processes in the model will be made available as a Centre for Policy Modelling Discussion Paper. The previous version of the model and its results will appear in Alam et al. (forthcoming). Below are brief descriptions of the key processes introduced into the model.

Sexual Network

Each agent is assigned an upper limit for the maximum number of concurrent partners they can have. This upper limit is based on an empirical study of sexual networks undertaken at Likoma Island in Malawi (Helleringer et al. 2007). Exogamy is implemented in the building of the sexual relations. Agents look for partners outside the nuclear family and immediate kin. Agents form heterosexual courtships based on the model for courtships and marriages described in Heuveline et al. (2003), Stanley (2006) and Todd and Billari (2003). Adult male agents look for possible female partners among their friends (and friends of friends) circle and may also propose courtship to the female agents randomly (a parameter). The choice preference of the male agents varies with respect to their ages. For instance, a young adult male would go for the attractiveness and similar age only. Attractiveness is a number assigned to agents (currently, log-normally) and a male agent looks for a female whose attractiveness exceeds their own aspiration level (assigned log-normally) as well. The aspiration level of the agents who fail to find female decreases over time, while for those satisfied with their current sexual partner(s), increase their level of aspiration. The female agents, if possible, choose from one of the proposers. The criteria changes with age. Young female agents are mostly interested in young adult males of similar age, while more mature female agents prefer proposers who have some employment as means to provide financial security.

There is a courtship waiting time in the model, for each agent. This has been adapted (a crude adaptation) from the work by Helleringer et al. (2007). If the couple passed the courtship threshold for both the agents, the male proposed the lebola to the female's household. For marriage, both female and male agents must be unmarried (or widowed in case of males), and the male's household must have the amount to present to the female's household. Marriages are monogamic, although male agents can have multiple sex partners at a time. For the female agents, the model assumes that once a female agent is married, they restrict their sexual activities only to their spouses.

HIV/AIDS Spread

Migrant agents are susceptible to contracting HIV/AIDS and are therefore assigned relatively higher incidence chance than those who have not migrated. To begin with, we have used the age and gender demographic data for the prevalence of AIDS from the Limpopo province. Gamma and Weibull distributions are used for introducing new cases of HIV in the community. HIV spreads among the sexual partners in the model at every tick. This is modeled as the probability of contracting HIV per 1000 sexual intercourses. As existing couples may break up over the course of simulation and new sexual partners are sought, the risk of spreading the disease increases in the population. Another factor of the spread of the AIDS in the community is the mother-to-child transfer.

Antiretroviral (ARV) Treatment

Without any drug interventions, there is typically 20-45% (including breast feeding) for a mother-to-child (MTC) HIV transfer. However, given the availability of drugs and regular treatment, the chance can be reduced to as low as 2%[3]. We have incorporated three different types of treatments outlined by the World Health Organization (WHO). This ranges from the minimum and least effective of single dose of nevirapine to the strongly treatment of the mother and the newly-born by azidothymidine (AZT) for 28 weeks. The chance for MTC varies given the treatment available to the villagers and has significant policy implications.

Infant Mortality

Infant deaths occur based on the infant mortality rate (IMR) for the Limpopo province.

Borrowing of Food

The module for borrowing food has been changed to the households' level as compared to the agents borrowing food individually.

Education

The chances of agents' get the primary, secondary, and tertiary education is derived from the data available from the RADAR organization. School fees are paid on monthly basis, and if the households are no longer able to afford, the children are pulled out from the school.

Piecewise Work

Richer households (a parameter) offer 'some' employment to fellow villagers as piecewise employment. Agent who has worked for an employer before is given preference otherwise the employment is given on the first-come basis.

More types of social relations

New relations are formed among the agents, defined by employment and churches (denominations) that the agents belong to. However, this is in early stages and further work is needed for this module.

Mining

The mining module is currently being developed with the feedback from our case study partners from SEI (Oxford). 'Outsiders' agents have been introduced (both skilled and unskilled) who seek employment in the mine near the village. These outsiders find female sexual partners from within the village and may stay on rent with some households in the village. These migrant mine workers may go elsewhere after some time and maybe replaced by new agents. Currently, we are gathering the necessary information to fill in the gaps in the module and replace the arbitrary assumptions with more realistic ones.

2.1.4 Modelling Techniques

For the ongoing development of the declarative model it is necessary to find a balance between the expressiveness of declarative modelling in Jess and the faster execution of Java code. In the last six months we have introduced two different means to achieve this goal:

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[3] AVERT (www.avert.org)

1. Reducing the number of facts in Jess' memory by removing facts when they are no longer needed.
2. Supplying Jess with direct access to model functionality by implementing user functions instead of relying on calls on the model object.

For the first case, we devised a class *DisposalPolicy*, which keeps track of which type of fact can be removed after how many ticks. To be able to be removed with a disposal policy, a fact needs to possess a slot with a time stamp, denoting its assertion time. The modeller can then specify when to remove such a fact by calling the *addPolicy()* method with the fact header, name of the time stamped slot and the wanted time lag as parameters. If no time stamped slot is specified, the default *timeStamp* is assumed. The disposal policy is executed at the end of every model step after running the Jess engine, ensuring that a time lag of 0 results in immediate removal.

For dealing with dynamic endorsements a specialisation of Disposal Policy has been implemented. The class *EndorsementDisposalPolicy* allows for the removal of endorsements by specifying the endorsement token (e.g. *is-similar*) and the time lag. All endorsement facts possess the default *timeStamp* slot. The following are example disposal policies used in the declarative model:

```
disposalPolicy = new EndorsementDisposalPolicy(engine);
disposalPolicy.addPolicy("MAIN::payment", "payment-date", 1);
disposalPolicy.addPolicy("MAIN::employment", "end-date", 1);
disposalPolicy.addPolicy("MAIN::job-application", 1);
disposalPolicy.addPolicy("MAIN::death", 0);
disposalPolicy.addPolicy("MAIN::death-in-hh", 1);
disposalPolicy.addPolicy("MAIN::membership-reminder", 4);
disposalPolicy.addPolicy("MAIN::marriage", 0);
disposalPolicy.addEndorsementPolicy("similar", 5);
disposalPolicy.addEndorsementPolicy("most-similar", 5);
disposalPolicy.addEndorsementPolicy("is-friend", 10);
```

For the second case we implemented the Jess user functions *(current-tick)* and *(dump)*. The former retrieves the current model tick while the latter "dumps" the text passed as parameter on the console. The *dump* function invokes the method of the same name on the model class. Since this method only prints to the console if the respective model parameter *showOutput* is set to true, this ensures that both Jess- and Java-generated model output can be toggled via the parameter. In addition, replacing the in-built Jess output function *(printout t)* with faster output in Java achieves a speed-up.[4]

Together, the two user functions allow for the model shadow fact to be removed from the left hand side of the majority of rules, resulting in a faster Jess execution as the complete Rete network doesn't have to be rebuilt every model tick.

2.1.5 Dynamic Network Analysis

Social systems do not remain in a stable state and are dynamic in nature. Events changing the structure of the network may occur any time during the simulation which might be missed when using global measures. Unlike physical systems, social processes tend to be modelled descriptively and validated qualitatively (Edmonds and Moss 2005). Agent-based models are validated qualitatively at micro level and the simulated trajectories are analyzed quantitatively. Keeping the number of nodes fixed could possibly increase the risk of type-II error or a 'false-positive' effect. For instance the clustering coefficient of the network is affected as agents are removed from the

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[4] With version 7 Jess provides direct access to Java's console output via *((System.out) println)*, so a mere speed-up could also have been achieved this way.

population and new agents are introduced. For comparing such dynamical social networks, we suggest analyzing the subgraph statistics and first results are presented below. Another aspect is applying the Kolmogorov-Smirnov statistics which was discussed in the last CAVES progress report.

Analyzing Dynamic Friendship Networks using Subgraph Characteristics

Faust (2006) compared networks of different sizes and domains by means of the subgraph and lower properties, i.e. nodal degree distributions and dyad census. Currently, we are looking into applying the triad census to inform how the networks have been generated over the course of a simulation run. The question we ask is whether such properties can help in identifying the dynamics and evolution of reciprocal ties among agents.

A comparison of global and subgraph network characteristics is necessary when a generative mechanism is introduced into the agent-based simulations. As observed by Milo et al. (2002), networks sharing similar global characteristics could exhibit varying local structures. Global properties of the dynamic network may inform about the robustness of the underlying processes. On the other hand, local properties can show the variability that may occur for different setups for the same processes. Notice that the endorsement-based mechanism for the friendship network is dynamic in the fullest sense. Not only do such ties vary over the time, as the agents' perception about others may change, but the population as a whole changes as well. An insight into the generated subgraph structures can give further insight into the dynamics of the network under different settings. We investigate the friendship network evolved through the endorsement mechanism in the declarative model for the South African case study.

Three different simulations were run, each with 24 households, but the number of agents at the start differed slightly for each case. For setting 'A', the maximum number of friends was set to 5 for any time during the simulation. Every agent maintains a list of acquaintances; an acquaintance maybe identified with multiple endorsements as mentioned before. In setting 'B', an agent's upper limit for the number of friends' was determined randomly from 6 to 12, when it is born. The third case, setting 'C' kept the same upper limit as in setting 'A', i.e. 5, but introduced two new types of relations: same-church and same-club. Agents being members of the same church could now identify other members with the same_church endorsement. Analogously, agents belonging to the same burial societies/funeral clubs in the population may endorse each other using the same_club label.

Interestingly, this mechanism allows for asymmetric friendship links. Due to the different endorsement schemes agents with a high similarity index do not automatically end up as mutual friends. Since the weights are assigned randomly, agent A might rate similarity high, while agent B rates it low, thus making agent A pick B as a friend but not vice versa. A sensitivity analysis of endorsement schemes and maximal number of friends showed that the latter is the key parameter here. Increasing this from the original 1-5 to a value of 6-12 resulted in a friendship network with a high proportion of reciprocal links.

Figure 1 shows the percentage of reciprocal links or mutual dyads for the evolved friendship network. For settings 'A' and 'C', reciprocity remained around 80-85%. The slight change in the percentage of reciprocal ties can be explained by the birth and death processes that cause the agents' population to change. This implies that around 20% of the friendship ties were asymmetric. Given two agents X and Y, who are acquainted with each other, X may be a 'stronger' friend of Y than the other way round. Such effect has been reported in various empirical studies on friendship networks where the maximum number of outgoing ties was set fixed during the surveys (Wasserman and Faust 1994). For setting 'B', where the maximum number of allowed friends was 12, the reciprocity shows an increasing trend reaching closer to 100%. This also shows a higher trend for reciprocity among the agents in this case. An observation is that reciprocity in all the three settings is stable during the 1200 time steps.

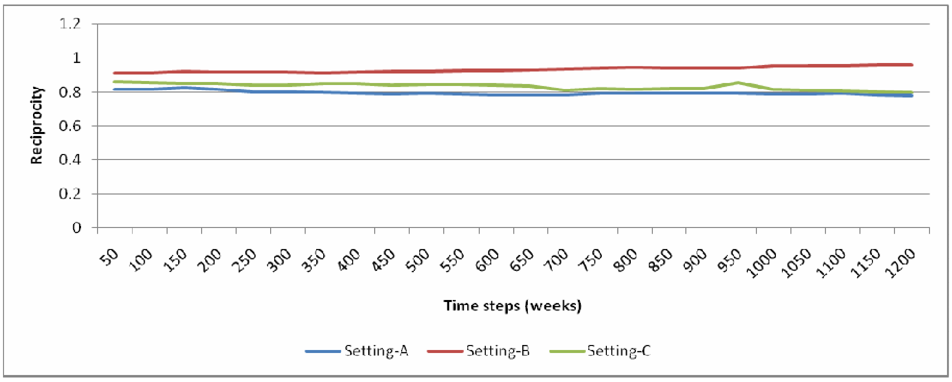

Figure 1: Proportion of reciprocal links (reciprocity) for the three simulation settings.

An important measure for transitive relations in a network is the clustering coefficient. It measures the proportion of ties between the nodes within each node's neighbourhood in relation to the number of links that could possibly exist between them (Watts and Strogatz 1998). Given a node (agent) X, the clustering coefficient measures to what extent two distinct neighbours of X are also linked to each other. With respect to the friendship network, it tells how often two friends of an agent are also friends of each other. The clustering of an entire network is given by the average clustering coefficient.

For all three settings shown in figure 3, the average clustering coefficient of the friendship network has an increasing trend during the simulation. The clustering coefficient for the first setting was the lowest compared to the other two. Interestingly, the friendship network in setting 'B' showed the highest clustering. One might conclude that the multiple affiliations for setting 'B' contributed more towards the average clustering of the network than the maximum upper limit for the number of friends. The high clustering in all the three settings strongly suggest the evolution of a 'small-world' effect. However, it requires multiple runs and further investigation to draw any conclusions.

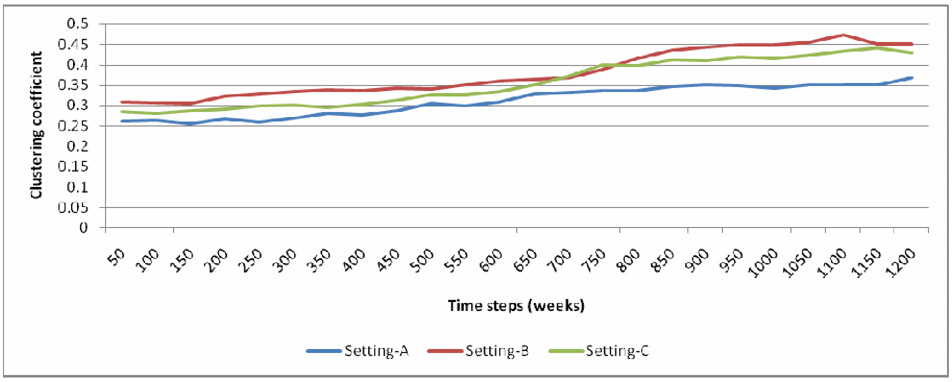

Figure 2: Average clustering coefficient for the friendship network for the three simulation settings.

Motifs are defined by Milo et al. (2002) as, "patterns for which the probability P of appearing in a randomized network an equal or greater number of times than in the real network is lower than a cut-off value" (e.g. p=0.01). Only statistically significant patterns are identified as motifs; those who are not but may be functionally important can be missed by this method.

We report the preliminary findings on the four most significant motifs of size 3 (i.e. triads) found in the friendship networks based on the z-score. The z-score is the original frequency minus the random frequency divided by the standard deviation. As next step, we would report on the complete motifs profile found in the respective networks. The adjacency matrices of the four triads are shown below.

000	**010**	**011**	**010**
001	**100**	**101**	**101**
110	**100**	**110**	**110**
motif-1	motif-2	motif-3	motif-4

Z-scores of the four above-mentioned motifs for the three simulation settings are shown in figure 3 (a), (b) and (c) respectively. In contrast to the fairly stable behaviour observed for reciprocity and transitivity, the three settings differ significantly for the motifs' z-scores. This observation supports the argument that networks sharing similar global characteristics may possess varying subgraph properties.

For the endorsement mechanism for the friendship network there is clearly a distinction in the trend when the maximum number of friends for agents is set differently. Interpretation of the presence of certain motifs and their role in the evolution of networks requires further simulation runs. For longitudinal studies of networks, it is imperative to monitor the stability of the measures applied each time. Endorsements are certainly only one of the many possible generative mechanisms for agent-based social networks. For such dynamical networks, subgraph analysis can reveal varying trends due to different setups better than average graph properties.

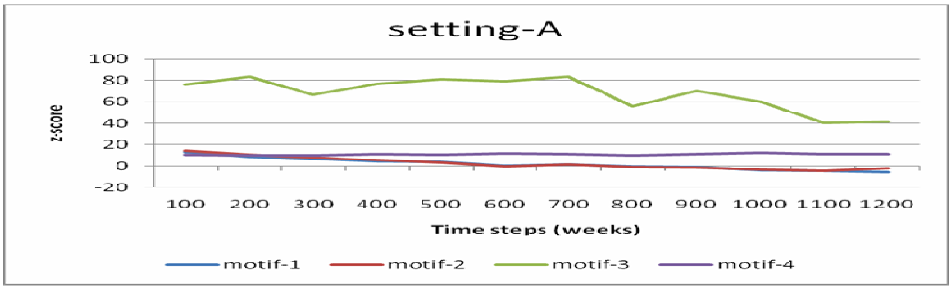

Figure 3 (a): Z-scores for the four significant motifs during the simulation for setting 'A'

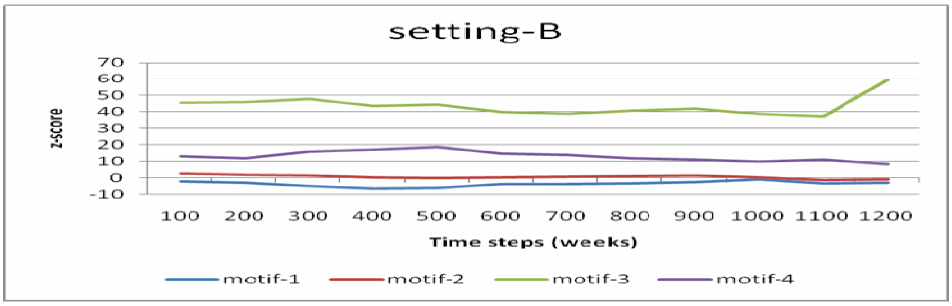

Figure 3 (b): Z-scores for the four significant motifs during the simulation for setting 'B'

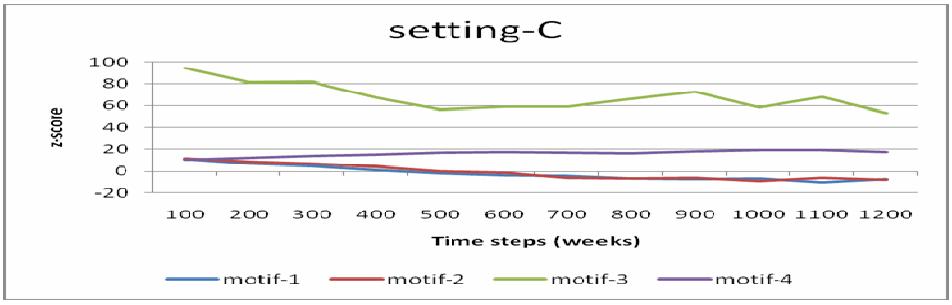

Figure 3 (c): Z-scores for the four significant motifs during the simulation for setting 'C'

For any generative mechanism that may be introduced for modelling agent-based social networks, merely looking at the average graph properties is not sufficient. Often, different setups lead to different subgraph characteristics in the networks, which may not be the case for global network properties. Subgraph analysis can be applied to networks with changing ties and nodes. The ratio in which the number of all possible subgroups in the 'real' or simulated network is compared to their random network counterpart (in terms of nodes and edges) is independent of the network's size. Thus, this technology is a good candidate for analyzing dynamical networks. A very important open question is whether the motifs identified in a dynamic social network can in fact be interpreted or not. Another issue that needs addressing is choosing the 'right' tick (step) for taking the simulation snapshots.

Essentially, an agent-based social network generated at every step may be analyzed separately in terms of the measures stemming from social network analysis and complex networks' properties. On the other hand, one may miss important events in a particular simulation of dynamic social networks, if the snapshots are just chosen at regular intervals, e.g. at every 50th or 100th time step. Eyeballing (using simulation visualization) helps in identifying the potential moments in the simulation where the snapshots taken may be significant. This approach has been used by Hales and Arteconi (2006).

2.1.6 Publications

In the period of March to September 2007, the following papers have been written:

- Shah Jamal Alam, Ruth Meyer and Emma Norling: *Agent-based Model of Impact of Socioeconomic Stressors: A DYNAMIC Network Perspective*. In: Proceedings of the Sixth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS'07), May 14–18, 2007, Honolulu, Hawai'i. . Online available at <http://www.aamas-conference.org/Proceedings/aamas07/html/AAMAS07_0049_854a4b13cd06518a2ef2dda1eb032981.xml>
- Shah Jamal Alam and Ruth Meyer: *Analyzing Network Evolution in Agent-based Models using Subgraph Characteristics*. In: Proceedings of the UK Social Network Conference, London, 13-14 July 2007, pp. 86-88
- Shah Jamal Alam and Ruth Meyer: *Structural Changes in Dynamical Networks Generated from Agent-based Simulation Models.* In: Proceedings of the Fourth Conference on Applications of Social Network Analysis (ASNA 2007), 13-15 September 2007, Zurich, Switzerland (forthcoming)
- Shah Jamal Alam, Ruth Meyer, Bruce Edmonds: *Signatures in Networks Generated from Agent-based Social Simulation Models*. Submitted to ESSA 2007. Online available as CPM Report No.07-176, <http://cfpm.org/cpmrep176.html>

- Scott Moss: *Alternative Approaches to the Empirical Validation of Agent-Based Models*. Online available as CPM Report No. 07-178 <http://cfpm.org/cpmrep178.html>
- Bogdan Werth, Armando Geller and Ruth Meyer: *He endorses me – He endorses me not – He endorses me…Contextualized reasoning in complex systems*. Accepted for the AAAI 2007 Fall Symposia, Washington, DC, November 8–11, 2007

2.1.7 Future Work

- Extend the declarative model to incorporate the mining scenario and allow for more statistical output to be collected in order to support evaluation of different policy measures.
- Continue work on social networks and statistical signatures.
- Apply model-to-model comparison to the declarative and procedural model. Model-to-Model (M2M) analysis has grown in recent years into a major research area in the field of multi-agent based simulations as more and more researchers from different backgrounds apply agent-based modelling to the same problems. As the M2M 2007 workshop website reads, "the specific aim of [M2M is] to sustain the development of techniques for comparing models used in social simulations or computational social science"[5]. One of the primary aims of such exercises is to identify suitable abstraction levels where model comparisons can be made across different scales, statistical signatures as macro-level output, and micro simulation results with regard to particular case-studies addressing similar social problems. The question we address is whether different styles of implementations – in our case declarative vs. procedural programming – lead to qualitatively different model results. The litmus test would then be to cross-validate (the combination of micro and macro validation) simulation results against the target system and analyse which of the two models, if any, provides a more plausible explanation of the social phenomena under investigation. Both the procedural and the declarative models would be compared on the basis of the models' assumptions, time-series output, and the statistical and structural signatures of the generated social networks.

2.1.8 References

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2.2 Universität Kassel

2.2.1 The research problem

The farmers in our case study area along the Odra river in Poland are caught in a social dilemma (Olson 1965; Ostrom 1990): While, in principle, the existing land reclamation system (LRS) of ditches and canals[6] can absorb the negative effects that extreme weather conditions have on the yields they attain, its proper functioning requires collective action (Dawes 1980) as regards maintenance.

More concretely, the maintenance of a local section of the LRS, if viewed independently from other channel sections, serves to alleviate or even eliminate negative effects such as excess water stress in the case of flooding, whereas neglecting the LRS maintenance only increases these effects even more. However, LRS maintenance must be regarded as a collective task that requires social mobilisation of the participants, i.e. the farmers whose land parcels are located along a ditch or a communicating ditch system. This is because the difficulties concerning land and water use in the Odra case study region result mainly from the fact that the conditions encountered on individual land parcels depend highly on the amount of LRS maintenance (and/or the sluice gate operations) performed on other (connected) land parcels. In wet periods, for example, LRS neglect leads to a loss of yield on neighbouring land parcels upstream since the runoff of excess water is blocked, whereas LRS maintenance has the opposite, beneficial effect since runoff is facilitated. The latter effect arises even if the upstream neighbours do not themselves maintain their section of the LRS (free riding). Downstream effects can be observed mainly in dry periods, if the LRS on a particular land parcel is not maintained (or the sluice gate on that parcel is closed). This causes a decrease in the amount of water flowing down to adjacent parcels resulting in a loss of yield on those parcels.

Maintenance of the land reclamation system thus enables to overcome environmental shocks like flooding and drought with only reduced yields or even with no losses at all, but it requires a collective effort. Yet, the collective action is undermined by the asymmetrical dependency which entails a social dilemma structure, in turn providing incentives for such problematic types of behaviour as free riding. It is expected that it is this social dilemma structure that hinders and in some cases prohibits the installation of a functioning LRS.

The obligation of LRS maintenance can also be met by a Water Partnership (WP). Water Partnerships are organisations which associate natural or legal persons in order to satisfy their needs regarding water management, including LRS maintenance. According to the Polish Water Law, a WP can be established by at least three legal or natural persons. The member of a WP is obliged to pay dues, which are proportional to the advantage he/she derives from WP activities. However, at the moment the WP in the research area is suspended. Members of local authorities are usually the

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[6] We use the term 'channel' both for canal and ditch.

leaders who create WPs. These actors play an important role in initiating and sustaining the formal institution of the Water Partnership.

2.2.2 Knowledge elicitation

In the selected representative target area our project partners from the University of Wroclaw conducted semi-structured qualitative interviews (Babbie 2001; Frankfort-Nachmias and Nachmias 1996) on the household level. The scope and form of questions (open-ended questions) focused on the reasons and conditions (e.g. IF milk production profitable) of different types of behaviour (e.g. THEN keep meadows) and covered the following issues: land use changes in the past, decision rules regarding land use, land reclamation system maintenance and collective action, social networks, and future scenarios. The population of concern consisted of all landowners living in three selected villages in the study area. The sampling frame was based on credible data on land ownership (including names, addresses and parcels' numbers)[7]. Therefore, it was possible to reach every land owner in the study area. Wherever possible, the interview was conducted with a person making decisions about the farm in order to ensure the credibility of the information elicited.

2.2.3 Abstracting the evidence: From storylines to actor types and actor decision rules

The primary output of the social field research (and guiding knowledge base for modelling) is a set of narrative storylines that is based on farmer interviews’ transcripts. The storylines consist of structured descriptions of farmers' past, present and future behaviour, reasoning and perceptions regarding land use and land reclamation.

Starting from the compiled storylines, a consultative abstraction and review process between case study researchers, domain experts and modellers was initiated. As an outcome of this process, a set of actor types and a set of stylised decision rules that describe their behaviour were derived.

Identification of actor types

In Poland, farming is still not only a business, but a tradition as well. This means that there are not only big production farms in Polish villages but also many small family farms that produce food only for their own needs. Accordingly, a first distinction of actor types is between commercial and small farmers. The interviews showed that the two types differ along several dimensions. Firstly, commercial farmers in the study area own approximately 20 to 40 ha of farmland and tend to expand by buying land whereas small farmers own less than 15 ha which they have usually inherited and see farming as a minor additional occupation. As indicated by the interviews, small farmers either leave their land neglected or they see themselves in a farming tradition and manage their small farms properly which sometimes includes LRS maintenance.

In contrast to the small farmers (having a main source of income other than farming) the commercial farmers strongly depend on the economic success of their farming activities. Due to their dependency on stable crop yields, commercial farmers are highly vulnerable to flooding and drought. Therefore, commercial farmers are well aware of the importance of LRS maintenance as a means of coping with water stress.

As the storylines suggest, small farmers have different motivations concerning LRS maintenance. In general small farmers state that they would either maintain the LRS if they had sufficient economic resources or if there was enough social support towards LRS maintenance. The economic dimension of LRS maintenance includes factors like buying the required equipment or paying others (or the WP) to do the work. Social support towards LRS maintenance may e.g. originate from observing other farmers maintaining their local LRS facilities properly and gaining

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[7] Abstract form land ownership registry, District Office in Legnica.

protection against environmental fluctuations and shocks. A second source of social influence originates from actors actively trying to initiate working Water Partnerships. Usually these WP initiators are people from local authorities. In addition, farmers could also be convinced by other persons, who are socially skilled and rather well known (high social network integration) as well as respected in the local community. Farmers mention e.g. professional advisors form Advisory Centres. As an abstraction we regard all these types of leader personalities as WP initiators in that they influence farmers in their decision to maintain the LRS and participate in the collective action.

Two level abstraction and analysis

In order to advance our understanding of the key processes underlying the phenomena observed in the case study we have engaged in a two level abstraction and analysis process, i.e. we pursue two lines of study using two separate versions of our model.

The first version only considers small farmers and the influence WP initiators have on a population of such farmers. It sets a focus on the study of the general properties of the relation between the social and the economic dimension of farmer decision making against the background of social network structures and the inherent interdependencies caused by the spatial location of land parcels. We have begun a more thorough examination of this model version which is expected to allow the identification of meta-phenomena of the observable dynamics like volatility, phase transitions, and possibly resilience as well as insights into their preconditions.

Whereas the first version resides on a more abstract level, the second version has been developed as an evidence-driven approximation of the actual situation in the case study. Hence, first and foremost, it adds commercial farmers who own considerably more land parcels than any small farmer – thus managing considerably more sections of the LRS – and always maintaining their LRS. Moreover, this version incorporates empirical data on the farmers' actual decision bias as well as the relative proportion of commercial farmers in the population of farmers as a whole.

In the following sections we describe the details of the abstract model version and show some initial results. However, the basic modelling principles are the same for both model versions.

Actor decision making

To abstract the drivers of farmers' behaviour, we follow the tradition of rule-based representation of problem solving and cognition (e.g. Anderson 1983). We model actors' decision making as production rules and use a reasoning engine to simulate the cognitive control structure. Our approach is to start out from the evidence given by the compiled storylines and derive individual rule sets for the identified actor types which then undergo confirmation by experts and stakeholders. Farmers' decision making about LRS seems to be the main source of complexity in the Odra case when coping with water stress. It touches aspects of social activation under conditions of a more or less fluctuating (hostile) environment. In addition, the environment sets complex hydrological inter-farmer dependencies. Therefore, despite the multi-facetted farmer decision making concerning various topics (land-use, LRS, high-level economic considerations like buying/selling land, leaving or entering farming business, etc.) we focus on a rather isolated examination of the socio-environmental dynamics of LRS decisions and keep the other decision dimensions constant (i.e. we assume that farmers continue farming with the same crop on the same land parcel).

As indicated, the model version described here focuses on the decision process of small farmers and not of commercial farmers. This is supported by the fact that commercial farmers always maintain their LRS. Thus for this actor type there are no decision dynamics about LRS. (Nevertheless, their "good example" or "success story" might influence other farmers' decisions).

Unlike commercial farmers, WP initiators (WPIs) play a direct role in the decision making of small farmers. As described above, a WPI has high social network integration and a good reputation. As an abstraction of this fact we assume that a WPI actor is able (1) to observe the economic success of farmers in his community and (2) to exert social influence towards LRS maintenance on all farmers in his community. Accordingly, we derive the following abstract decision rules for the WPI actor:

- IF significantLossesOfAtLeastThreeFarmers THEN initiateWP
- IF WPExists THEN askFarmersToJoinWP
- IF noSignificantLossesOfFarmers THEN stopAskingFarmersToJoinWP

As motivated, social and economic considerations are the main drivers of farmers' decision making regarding LRS. Thus, we seek to explicitly represent these dimensions (see the model description in the next section) and determine rules that model the relevant behaviours including the binary decision about participation in the collective action of LRS maintenance. The basic reason for maintaining LRS is of economic nature and relates to losses in crops in case of flooding or drought. The majority of farmers are aware of the relation between the state of the LRS and yields (although they are not able to quantify the interdependency precisely). The derived abstract decision rules relating to farmers' economic success are:

- IF notMaintaining AND sufficientEconomicSuccess THEN doNotMaintain
- IF maintaining AND sufficientEconomicSuccess THEN doMaintain
- IF notMaintaining AND veryLowEconomicSuccess THEN doMaintain
- IF maintaining AND veryLowEconomicSuccess THEN doNotMaintain

This strategy is reminiscent of the Win-Stay, Lose-Change decision heuristic as described by Liebrand and Messick (1996).

In addition to the farmer-internal dimension of economic success, external social factors influence farmers' decision making. The following rules deal with aspects of social influence:

- IF askedByInitiatorToJoinWP THEN doMaintain
- IF notMaintaining AND manyOtherFarmersMaintainLRS THEN doMaintain

To capture the aspects of social influence involved in these rules we use concepts of general opinion dynamics (cf. Latané 1981; Friedkin 1998). We assume that farmers are exposed to social influence towards or against LRS maintenance. Social influence is exerted through the ties of a farmer's social network. Sources of social influence are either other farmers holding a certain view on LRS (pro/con) or an active WPI actor asking to join the WP. Implementation details are given in the modelling section below.

The decision rules of the WPI actor are straightforward: The actor observes the farmers in its community and initiates a WP if required. Then it starts promoting LRS maintenance until "things improve".

2.2.4 Model Description

The overall computational model consists of two sub-models. SoNARe, the main sub-model, aims to capture farmer decision making and some of the main social characteristics of the Odra case in an agent-based model. The second sub-model is a simple and abstracted hydro-agricultural model that reflects the main environmental characteristics of the target region. It provides the SoNARe agents with feedback about hydrological dependencies and crop yields under fluctuating climate conditions in the simulated area.

The central problem features that may be derived from the previous section and which the two sub-models are to jointly capture can be summarised as follows:

- Social network integration: The different actors are connected via social networks in which they propagate their opinion concerning LRS maintenance and perceive that of others.

- Actor types: To examine the collective dynamics that drive farmer decision making pertaining to the LRS, two actor types are considered, namely a prototype farmer (landowner) and a Water Partnership initiator (WPI). WPI actors are leader personalities with a high reputation and a high degree of social network integration that actively trigger social activation towards LRS maintenance. Farmer actors keep a balanced attention to their economic success indicated by their attained crop yields and their social endorsement resulting from their opinion regarding LRS maintenance.
- Actor decision rules: The behaviour of the two considered actor types is defined by two sets of decision rules. For WPI actors the rules reflect their reasoning about when to trigger collective action and for farmer actors the rules reflect their decision making about partaking in LRS maintenance under social and economic considerations.
- LRS maintenance: There is a functional relationship both locally and globally between the maintenance (or neglect) of the LRS and the yields on individual land parcels.
- Spatial dependencies: The functional relationship is mainly determined by upstream and downstream spatial dependencies of the land parcels along ditches and channels.
- Extreme weather conditions: The effects of LRS maintenance and their impact on yields are most crucial under extreme weather conditions.

The SoNARe Model

Basic modelling concepts

We follow a rather strict distinction between the physical environment and the social environment of the agents. This distinction focuses on a separation between physical and social spaces both in terms of semantics and techniques used for their representation. For various reasons, the simulation of the agents' physical environment uses a traditional grid based approach. The social "location" of an agent is given by his position within a social network context, where an agent is viewed as a node and social relations are represented by edges. In general, agents may be considered to be embedded in more than one social context and thus an agent's social environment may consist of more than one network layer. The modelled agents' perceptions vary related to their physical or social environment. Both types of perception are locally bounded in terms of a perceivable section of the surrounding physical space and in terms of network edges and neighbouring nodes (cf. Pujol et al 2005). In the same way, the agents' repertoire of actions differs relating to their respective environment.

In the current model version, the actions related to the natural or physical environment have been reduced to the farmer agents' binary decision of participating in the water partnership and therefore locally maintaining the LRS or not. Feedback from the simulated environment is perceived in the form of a farmer's attained yield over a number of years. The farmer agent keeps a record of a stylised economic balance that reflects the varying yields.

The agents' social environment is modelled as networks. An agent may be seen as a node in different social network contexts. Unlike in other network modelling approaches, agents do actively perceive their social environment and are enabled to act in their social network. In the work presented here, we investigate the exertion and perception of social influence as ways of "acting in" and "perceiving" a given social environment. Moreover, in order to clearly isolate the effects of possible topological network dynamics (adding or removing edges), we use a one-layer and static social network. Therefore, this network only serves as the infrastructure for perceiving and exerting social influence.

Agents

Social and physical environments Against the background of the modelling concepts described in the previous section, the two agent types used in the presented version of the SoNARe model differ distinctly in the ways they are embedded in their social and physical environments. In the model, farmer agents and the WPI agent are embedded in a common acquaintances network. The evidence that a WPI has a high degree of social network integration is covered by the fact that the WPI agent is linked to all farmer agents (in a star-like manner) whereas farmer agents possess direct social links only to a fraction of other farmer agents (but the social links could span a number of hydrologically independent ditches or channels). As the Odra case study suggests, most WPI actors are not farmers themselves, they are e.g. village mayors or external advisors. Therefore, in the model WPI agents do not directly interact with the simulated physical environment. By contrast farmer agents continuously interact with the simulated environment by performing local LRS maintenance and by obtaining feedback about attained crop yields.

Perceptions of social support and economic success It has been motivated that the agent-based model has to allow for explicitly contrasting social and economic influences on a farmer's decision process with regard to LRS maintenance. To this end, two internal perceptions are modelled for farmers, namely economic success and social support.

- The perception of economic success (*economicSuccess*) is determined by several factors: First of all, each year a farmer agent appraises its current yield as either "good" or "bad" with respect to a fixed yield perception threshold. Accordingly, it then stores either a positive value ("good") or a negative value ("bad") in its yield memory. The capacity of the memory is fixed for one agent but it may vary across individual agents[8]. Appraisal is symmetrical in the sense that the value for a "good year" and the value for a "bad year" cancel each other out exactly. The sum of all the stored values in yield memory then constitutes the agent's current perception of economic success.
- The perception of social support (*socialSupport*) is a function of the agreement/ disagreement between farmer and acquaintance concerning LRS maintenance. An agent receives a signal of support from each acquaintance that shares its strategy in that year, whereas it receives a pressure signal from each agent that uses the opposite strategy. Signals of support or pressure may also originate from an active WPI, see below. The exertion of social influence is strictly symmetrical in the sense that a signal of support and a pressure signal sent by the same farmer agent are identical in magnitude[9]. Thus, in addition to the impact of the actual yields the model also reflects general opinion dynamics amongst farmers (cf. Latané 1981; Friedkin 1998).

From the above definitions it is obvious that the magnitude of the perceived economic success depends on an agent's memory capacity, because it limits the number of positive or negative memories that may be stored. Similarly, the magnitude of the social support perception varies depending on an agent's social network integration, i.e. the number of acquaintances influencing it. We therefore define an agent-specific normalisation for both *economicSuccess* and *socialSupport* such that they can be compared on a common scale. Normalisation is done in a straightforward manner by making use of the fact that both dimensions are symmetrical with respect to 0. We then map each onto the co-domain [0,1] such that values below 0.5 represent "negative economic success" and "negative social support" respectively while values equal to or above 0.5 reflect positive perceptions in these respects. Concretely, the following agent-specific normalisations are

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[8] The distribution of memory capacities among farmer agents is defined by a mean value and a deviation radius in years.

[9] However, each signal is weighted by the individual level of social influence of the acquaintance sending that signal. In the presented model farmer agents have identical levels of social influence whereas WPIs have a higher level.

performed.

$$norm(economicSuccess) = \frac{economicSuccess + maximumEconomicSuccessPossible}{2\ maximumEconomicSuccessPossible}$$

with *maximumEconomicSuccessPossible* defined as the agent's appraisal supposing it recalled only good years. Say the agent has a memory capacity of 5 and appraises good years with a +1 and bad years with a -1, then *normEconomicSuccess* ranges from (-5+5)/10 = 0 to (5+5)/10 = 1.
Similarly, social support is normalised as follows:

$$norm(socialSupport) = \frac{socialSupport + maximumSocialSupportPossible}{2\ maximumSocialSupportPossible}$$

with all farmers having the same level of social influence (set to 1) and the level of social influence of the WPI being defined as some multiple thereof. Currently, for instance, the WPI's influence level is set to 3, i.e, other things being equal the WPI is three times as influential as a farmer. So, say an agent is influenced by 10 farmers and one WPI, then its normalised range of social support goes from (-13+13)/26 = 0 to (13+13)/26 = 1.

Decision making The WPI agent being embedded in the social acquaintance network also partakes in the general opinion dynamics as regards LRS maintenance and the magnitude of the social support it exerts is defined in relation to that of farmer agents. It is assumed that the WPI possesses information about the economic success of its acquaintances, i.e. the immediate network neighbours in the social network. A WPI agent decides to exert its social influence in favour of LRS maintenance whenever it perceives at least three farmers who have big losses; i.e. farmers whose individual economic success is below 0.5. The WPI does not exert any influence otherwise.
As an example the rule that implements the WPI's decision to start exerting social influence in favour of LRS is shown below:

```
(defrule exertInfluence
      "WPI exerts influence in favour of LRS maintenance once it knows of at
      least 3 farmers who have big losses"
      (wpi (OBJECT ?wpi) (id ?id))
      (factFarmersWithBigLosses (wpi ?id)
       (number ?num&:(>= ?num ?*WPI_ACTIVATION_THRESHOLD*)))
      =>
      (call ?wpi setExertInfluence TRUE)
)
```

When modelling the decision making of the farmers the individual balance between economic and social considerations has to be reflected. We implement this balancing based on the above introduced perceptions of economic success and social support by adding a parameter that reflects the (socio-economic) decision bias that a farmer has. Since the two perceptions are normalised, weighting their influence on the decision process is straightforward. We introduce the *decisionBias* of a farmer as a value in the range of [0,1]. Values above 0.5 stress the economic influence on decision making, values below 0.5 stress the social dimension.

The following decision rule gives an example of how *economicSuccess* and *socialSupport* are combined using the *decisionBias* parameter to model farmer decision making regarding LRS.

```
(defrule changeLRSMaintenanceStrategy
      "change LRS maintenance strategy when social support is low and economic
      success is low"
```

```
      (declare (no-loop TRUE))
      (farmer (OBJECT ?farmer) (id ?id)
       (currentSocialSupport ?currentSocialSupport)
       (currentEconomicSuccess ?currentEconomicSuccess)
       (decisionBias ?decisionBias)
       (maintainLRS ?maintainLRS))
      (test
       (< (roundToDecimalPlaces 2
         (+
                (* ?currentSocialSupport (- 1.0 ?decisionBias))
                (* ?currentEconomicSuccess ?decisionBias)))
       0.5))
      =>
      (call ?farmer setMaintainLRS (not ?maintainLRS))
)
```

The Simple Hydro-Agricultural Model

The Simple Hydro-Agricultural Model (SHAM), developed by our project partners at the Wroclaw University of Technology, is a quasi two-dimensional abstraction of the environmental situation typical for the Odra region (see Figure 1). It reflects the hydrological dependencies between neighbouring landowners and simulates the effects of different weather conditions, LRS maintenance and LRS neglect as well as sluice gate operations on the water levels, different land uses and the crop yields of individual land parcels along a channel.

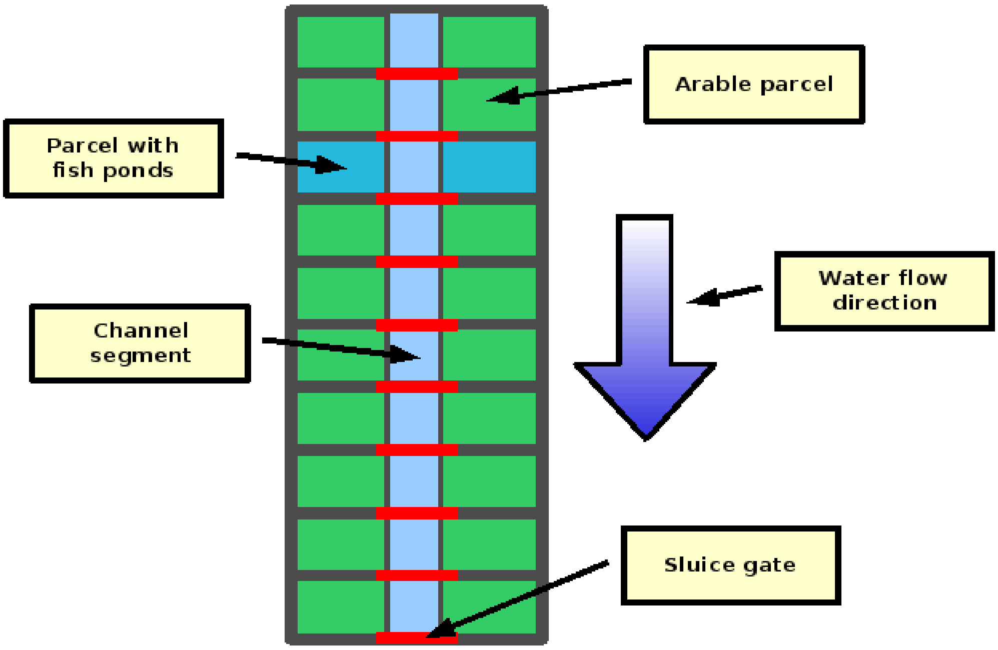


Fig. 1. Schematic diagram of the abstracted environment.

The outputs of the Simple Hydro-Agricultural model were -- on the given level of abstraction -- validated with stakeholders and experts. The main modelling assumptions and simplifications that were made for this sub-model are:

- The simulated environment has a quasi two-dimensional topology.

- Parcels are homogeneous in terms of area and hydrological properties. They may differ in terms of land use and the condition of the channel.
- Sluice gates are located along the channel, at the bottom of every parcel
- The simulation time step is one month. Monthly average water levels are calculated for each parcel.
- The terrain has a small, homogeneous slope along the channel's axis.
- Parcels that are at the bottom of the slope tend to have higher water levels, than those at the top. This effect is referred to as the "topographic effect".
- Weather conditions are the same for all parcels.
- Weather conditions in one year do not influence the amount of water in the system in the next year.

At the end of every simulation year, the model calculates stylised yields from every parcel depending on the selected land use. A farmer agent that operates on a given parcel can perform certain operations like cleaning the segment of the channel located on its parcel, or closing/opening a sluice gate. Yields depend on the land use type and the average water level in a given parcel. Because the model handles some spatial effects, like water lifting due to a clogged segment of the channel, or a closed sluice gate, the yields are affected not only by phenomena taking place on a single parcel, but also by those which happen in the surroundings.

The hydro-agricultural model offers a number of parameters to be varied across simulation runs. These parameters allow setting e.g. the current weather conditions, channel length, number of land parcels or LRS condition on a specific parcel. Furthermore various output data are provided by the model e.g. annual crop yields, water levels or the present LRS condition. For our purposes the following features were used:

- Weather sequence. A repeated sequence of normal, wet and/or dry years is used to set the weather condition per simulation year.
- Land parcels. The number of land parcels per channel and the type of land use of each land parcel can be set. Currently, the hydro-agricultural model allows for two types of land use, namely arable and fishpond, of which only the former is used in the simulation runs presented here. Each land parcel is managed by one and only one farmer agent.
- Crop yields: Crops for arable land parcels are being planted in month 5 and harvested in month 10. At the end of a simulation year farmer agents are provided with the amount of crop yield on their respective land parcel.
- LRS maintenance: Farmer agents can change the LRS on their land parcel. The condition of the local LRS slowly degrades when it is not maintained and (at present) it fully recovers within a month of an agent first maintaining it.

Finally, we scale up the model to a reasonable number of land parcels (and thus agents) by assuming a fixed number of parcels per channel and increasing the number of channels. Increasing the number of land parcels per channel is not backed by observation, i.e. it is unrealistic to assume a channel size well in excess of ten parcels. The up-scaling is achieved by instantiating the hydro-agricultural model multiple times and simulating a number of channels in parallel without any hydrological interrelations among them.

Model execution cycle, sequence of events

For each year the model executes the following sequence of events: In month five the hydro-agricultural model simulates the planting of crops for each land parcel and in month ten it simulates the harvesting of these crops. Finally, at the end of every year, the agent-based model is run performing the following sequence of steps: all agents perceive and memorise their individual yields, exert their social influence, perceive the social influence exerted on them, re-rate their economic success and then make their decisions for the next year. It is important to note that agents are synchronised at every step. Most importantly, this means that agents take their decisions simultaneously.

Implementation

Technically, the SoNARe model is a hybrid model. The modelling infrastructure (scheduling, data logging, visualisation, etc) is provided by the RePast agent programming framework (Recursive Porous Agent Simulation Toolkit, cf North et al 2006). The cognitive control structure and decision making of farmers and WPI actors is modelled using production rules implemented in JESS (the Java Expert System Shell; http://herzberg.ca.sandia.gov/jess/), and JESS's reasoning engine. This is consistent with a long-standing rule-based representation of problem solving and cognition (Anderson 1983). It opens the possibility to provide Repast agents with cognitively plausible capabilities. Since JESS is written entirely in Java and allows for calling Java methods from rules, it integrates well with the Repast toolkit. JESS consists of a rule interpreter which can apply both forward and backward chaining, using an improved version of the fast but memory-intensive RETE algorithm (Forgy 1982) to match facts from the fact base to rules in the rule base. Declaring facts and rules is done via a script language with a LISP-like syntax.

The model uses one shared RETE engine for all agents. The rule base is initialised with a commonly shared set of decision rules for each of the agent types. The agents are added as shadow-facts (i.e. references to Java bean representations of agent objects in RePast) to the rule engines' working memory. When an agent updates its perceptions of social support and economic success (this is scheduled once a year), the Java property-changed-listener will mark the corresponding fact in the RETE net as modified. The matching engine of JESS is then run at every simulation step and uses the decision rules to derive the next decision of the individual agents. Actions are buffered and later executed by the RePast part of the model. Furthermore, the RePast portion of the model provides the necessary functionality to interface with the hydro-agricultural model. Figure 2 illustrates the model architecture.

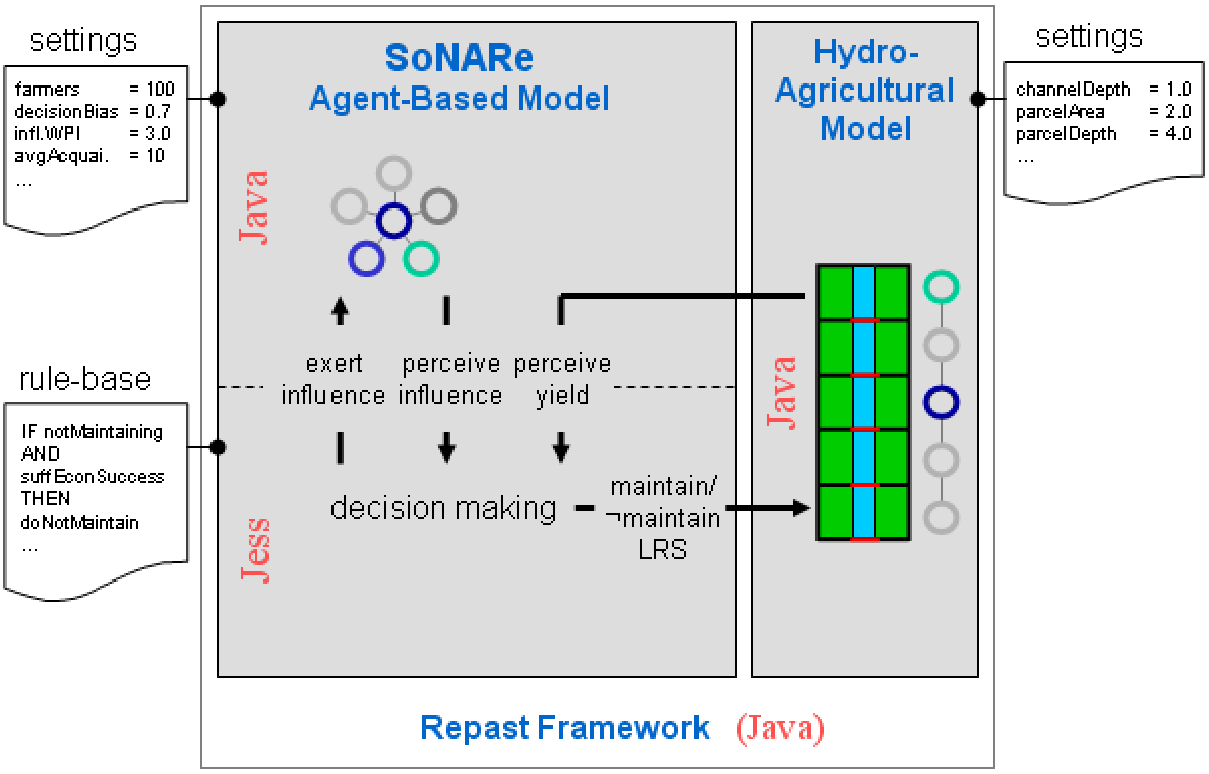


Fig. 2: Overview of the integrated model architecture.

2.2.5 Simulation results

All simulations are initialised with rows of ten land parcels that are located along one channel. It is assumed that each land parcel is owned and managed by exactly one farmer and that each farmer owns and manages exactly one land parcel. Farmer agents' decision making is implemented by the set of decision rules described above which are identical for all farmers. All agents appraise their crop yield as "good" or "bad" with respect to the yield threshold of 9. The agents' yield memory capacity, however, is heterogeneous; it is randomly assigned with a mean value of 5 years and a radius of 2 years, i.e. farmer agents "recall" between 3 and 7 years. A farmer agent's memory capacity remains fixed over the whole simulation run and is identical for all presented scenarios. The model is scaled up to simulate 100 farmers in order to have a more realistic population size for the underlying acquaintance network. As stated above we scale up the model by increasing the number of channels.

Farmer agents and WPI are embedded in a common social network. Farmer agents continuously exert social influence over their network edges with a level of 1 per outgoing edge. In the simulations shown here we assume one WPI agent that becomes active if at least 3 farmers have big losses and accordingly it becomes passive again if less than 3 farmers have big losses. The WPI possesses social network ties to all farmer agents and when active, it exerts social influence with an influence level set to 3 towards LRS.

All three scenarios start off with no LRS maintainers and the same distribution of memory capacities. Furthermore, the same weather sequence is used throughout: Two years with normal weather conditions are followed by one year of wet weather. This pattern is then repeated for the whole run.

Even though months are the smallest simulation step considered in the model, all performance diagrams show yearly averages, because the results shown here focus only on agent decision making about LRS maintenance, which is done once a year, and not on farming activities during a year.

Due to the model's level of abstraction, it has to be stated that the simulation results shown here do not claim to be exact predictions or forecasts of future developments. E.g. when results are discussed in terms of years until a certain process has finished, this should be interpreted as being in reference to an abstract time span of "model" years. Nevertheless, scenarios may be compared with respect to differences in temporal dynamics.

5.1 Scenario 1 – Baseline scenario

In the baseline scenario, the farmer agents' decision bias parameter is set to 0 meaning that decision making does not consider economic factors. Furthermore, the social influence level of the WPI agent is set to 0, i.e. it does not exert social influence. Thus, as the simulation starts off with no LRS maintainers agents do not change their LRS maintenance strategy (they never maintain).

Figure 3 shows the farmers' yield statistics over the simulation period. Because all farmers keep to their passive LRS strategy, a repeated pattern of yield losses every third (i.e. wet) year can be observed. Furthermore, under wet weather conditions the mean deviation of the farmers' yields is much greater than in normal years. Figure 4 reveals that in cases of flooding and all farmers neglecting their LRS the yields of farmers at the top of the channel are considerably worse than the yields of those further at the bottom. Thus, the hydro-agricultural model shows that under flooding conditions farmers located further downstream obtain a certain degree of implicit flood protection if upstream neighbours neglect their LRS and thus absorb most of the effects of flooding. Moreover, the farmers at the bottom experience only minor differences between normal years and wet years in this scenario.

The baseline scenario demonstrates that given farmers do not regard LRS maintenance as a means of coping with extreme weather conditions (due to a lack of knowledge or simply due to passiveness) the implicit spatial and hydrological dependencies between farmers have a high impact in two different dimensions. Firstly, the overall average of attained crop yield is lower than under different assumptions (see scenarios 2 and 3). Secondly, the attained crop yields vary distinctly on neighbouring parcels along a channel as a result of the hydrological dependencies which in turn may be interpreted as a source of dissonance between individual farmers.

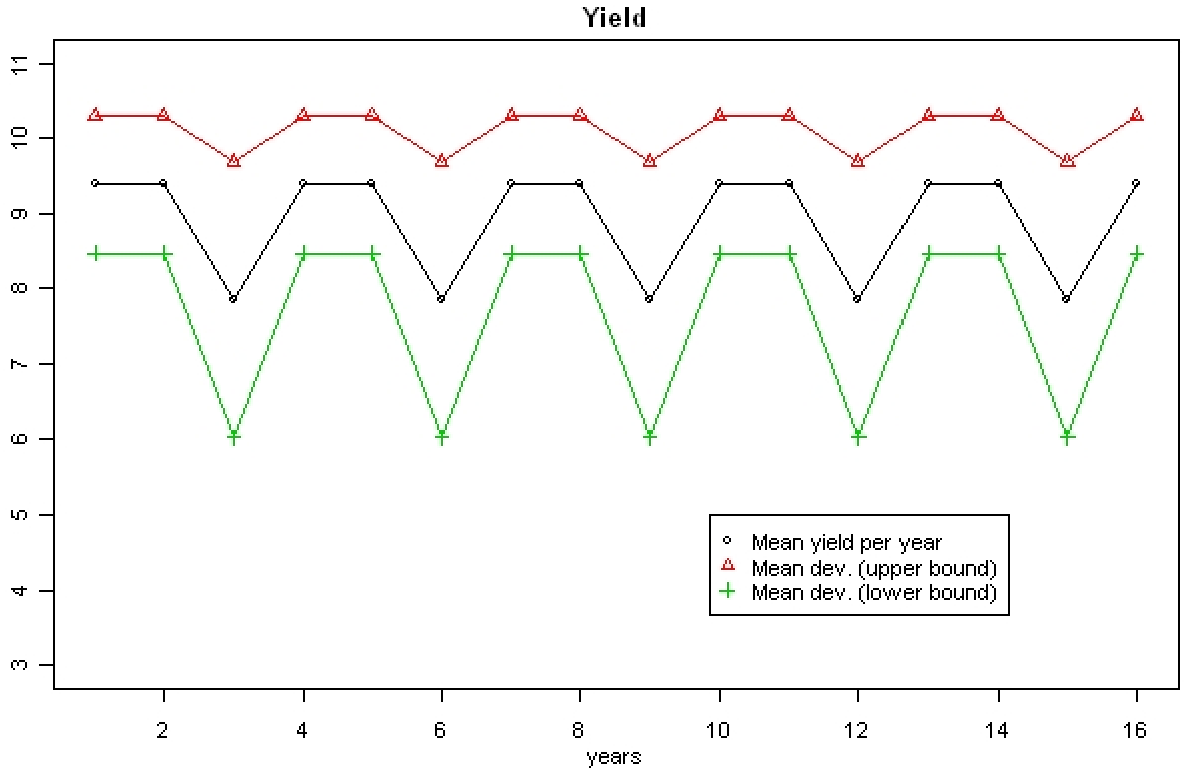


Fig. 3. Average yields of farmers over sixteen years bounded by the mean deviation.

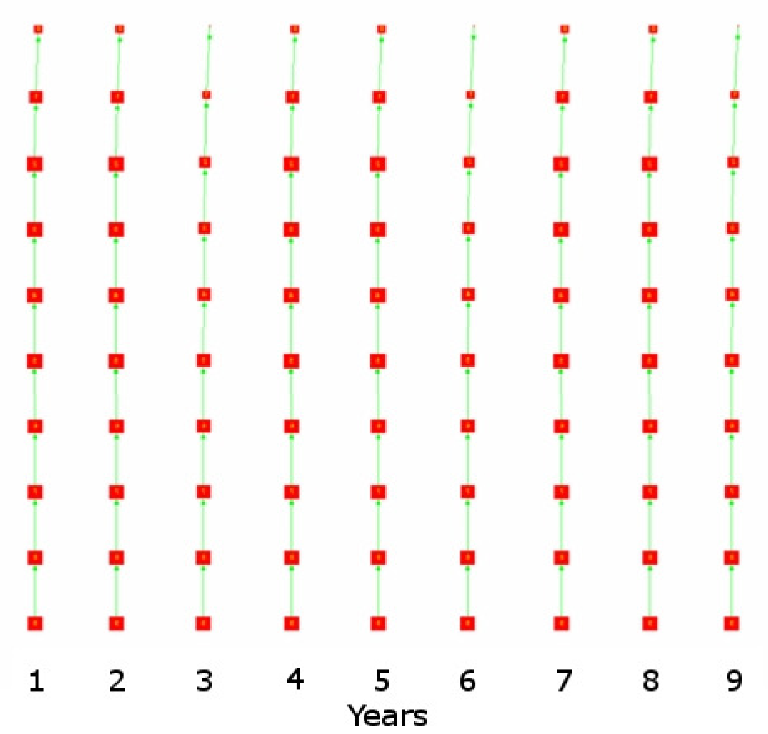


Fig. 4. Yields and LRS strategies on individual land parcels along one channel over time (years 1 to 9). Because the baseline scenario excludes decision dynamics each of the ten simulated channels shows identical results, therefore we only show one of the channels. Land parcels are represented as squares connected by green lines indicating the dependency relation (flow direction from top to

bottom). The size of each square is proportional to the yield for the respective land parcel. The red colour indicates LRS neglect.

Scenario 2 – The influence of economic success

This scenario differs from the baseline scenario in that the farmer agents base their decisions on their perceived economic success. Accordingly, the decision bias parameter is set to 1 so that social considerations do not influence farmers' decisions. Thus, the WPI does not have any influence on the decision making. Even though in this scenario farmers' decisions are driven solely by the subjective perception of their respective economic farming success, farmers' decisions may well affect other farmers' economic success (due to the hydrological dependencies indicated in the previous scenario) and feed back to the decision dynamics.

Figure 5 shows the development of LRS strategy adjustments over time, i.e. the proportion of farmers who change their opinion about LRS maintenance in either direction. This volatility indicator increases for about 7 years of simulation time and then gradually falls back almost to zero. Figure 6 depicts the corresponding convergence of the number of LRS maintainers to nearly 80% after about 30 years.

The fact that the volatility indicator does not fall back to zero (see years 35-40) was further investigated. For that purpose 100 independent simulation runs over 80 (instead of 40) years were conducted. The results confirmed the perception that (in the given scenario) the fraction of LRS maintainers stabilises at approximately 80% with 1% to 6% of agents continuously adjusting their LRS strategy. It seems that this small fraction of farmer agents has a perceived economic success very close to the decision threshold of 0.5. Therefore these agents frequently switch their opinion about LRS while the vast majority of agents stop adjusting their strategy after 30 to 40 years.

Figure 7 shows an increase in the average of farmers' crop yields. Furthermore, the mean deviation of crop yields in years of flooding decreases from (approximately) 2 to 1. Similar observations can be made for normal years.

As may be seen in Figure 8, the perceived economic success of LRS maintainers increases substantially and then settles on a slightly higher level than the corresponding values for non-maintainers. Finally, Figure 9 illustrates the spatial distribution of opinion shifts over time. In the course of the simulation, the topmost farmers are the first to start maintaining their LRS after a wet year. This is probably due to the combination of the positional disadvantage even in normal years (see scenario 1) and the bad yield in a wet year.

Scenario 2 illustrates the dynamics of farmer decision making given that farmers appraise their economic success and change their opinion about LRS accordingly. After a phase of volatility, a big majority of farmers starts to continuously maintain the LRS. On the population level this results in an increased average of attained crop yield while yields are more evenly distributed among individual farmers resulting in a reduced dissonance between farmers when compared to scenario 1. However, the economic incentive (alone) is not sufficient to mobilise all farmers. Instead a minority of approximately 20% shows free-riding behaviour: For the free-riders the perceived economic success does not drop far enough to make them change their mind because they benefit from the LRS activity of their neighbours.

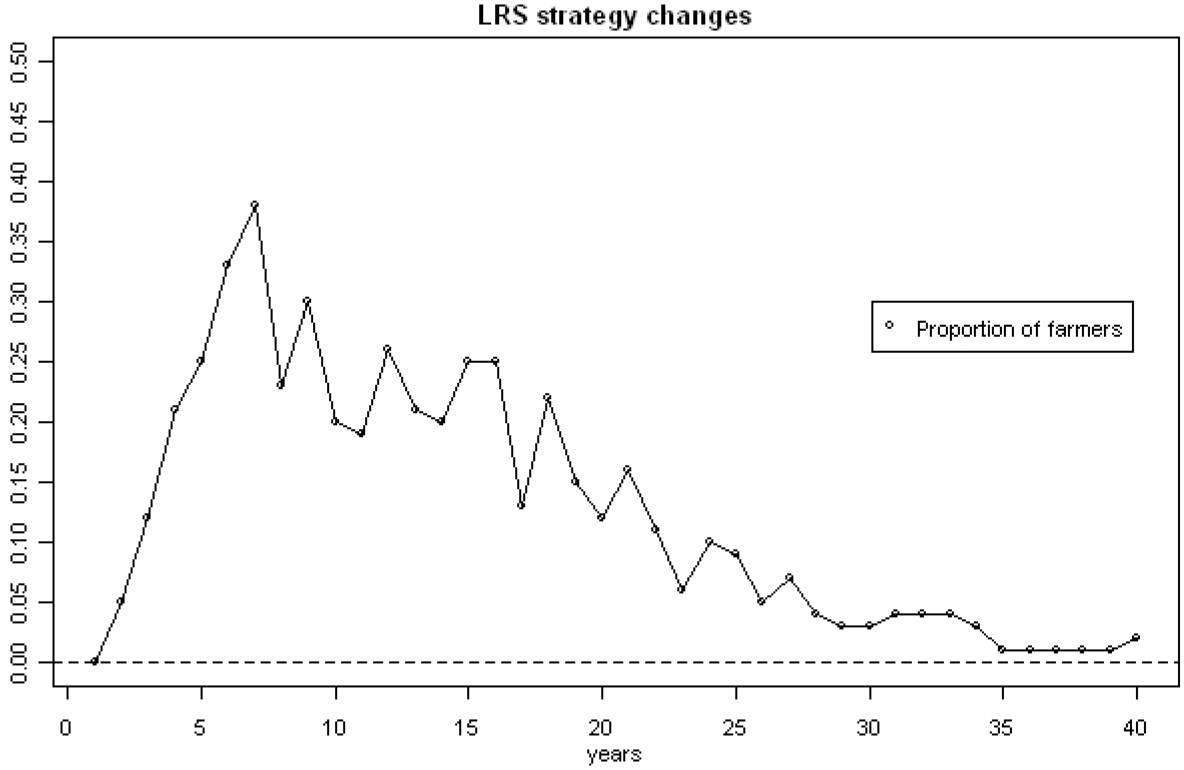


Fig. 5. Strategy changes over time as an indicator for volatility. Each dot marks the proportion of farmers who have switched their LRS strategy in one year (40 years in total). Note that the change can be either way, i.e. in favour of or against LRS maintenance.

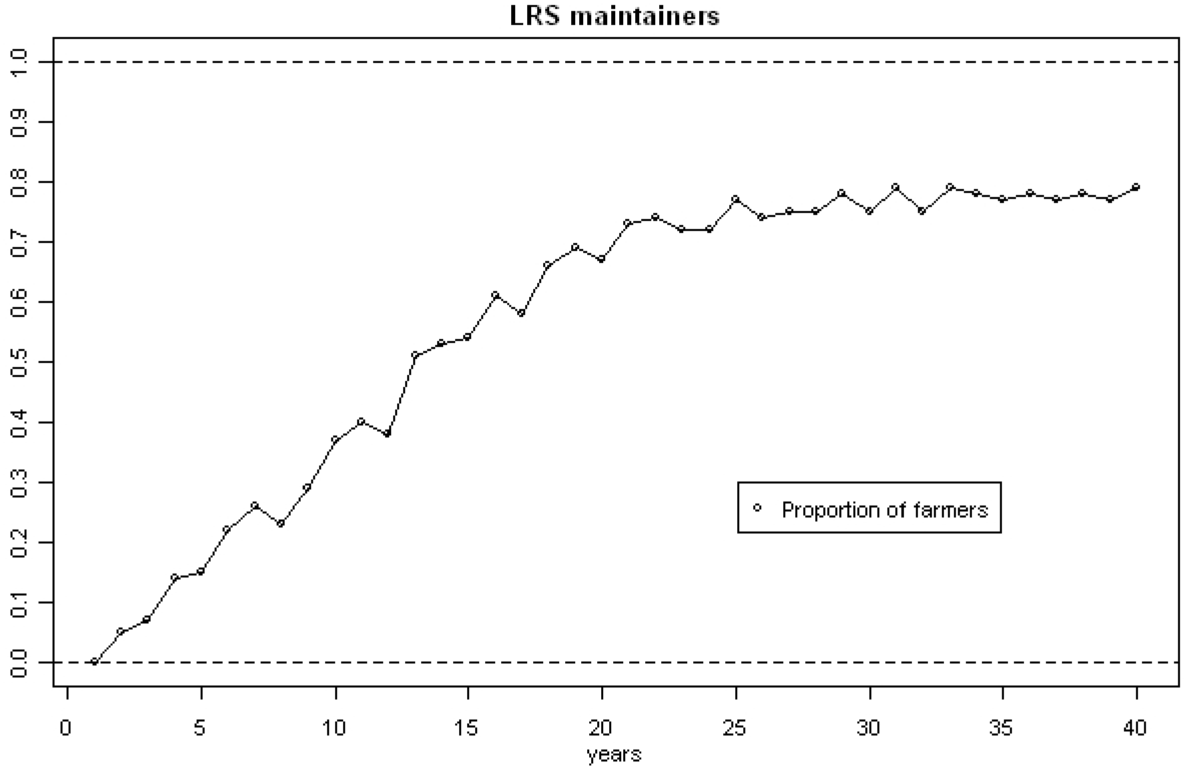


Fig. 6. Proportion of LRS maintaining farmers over time.

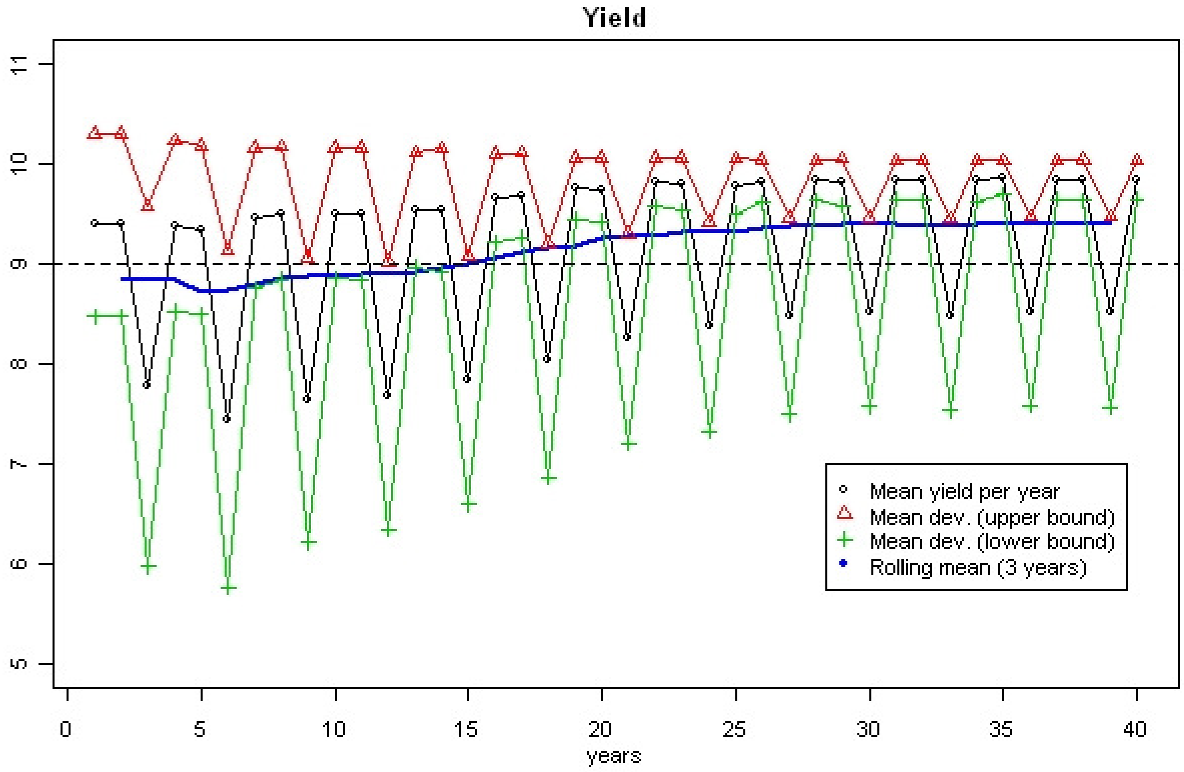


Fig. 7. Average yields of farmers bounded by the mean deviation and the rolling mean over three consecutive years.

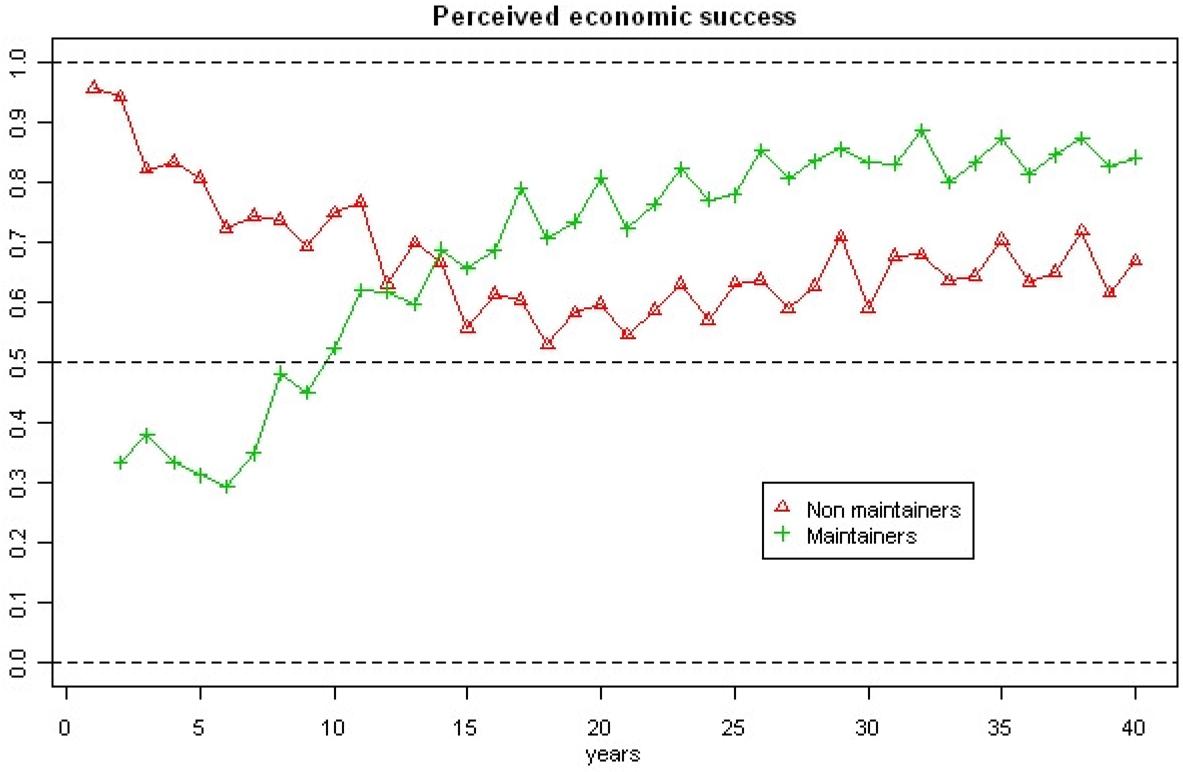
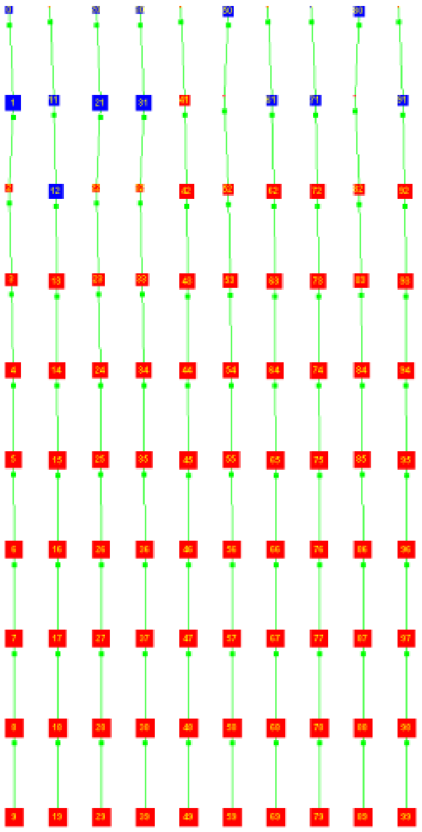
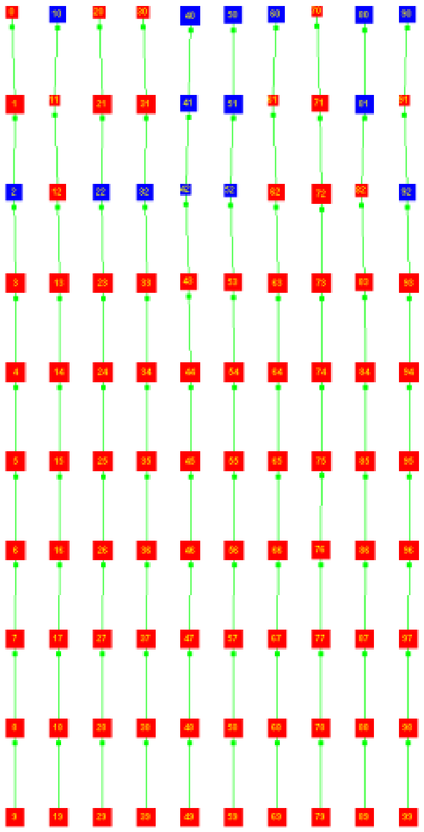


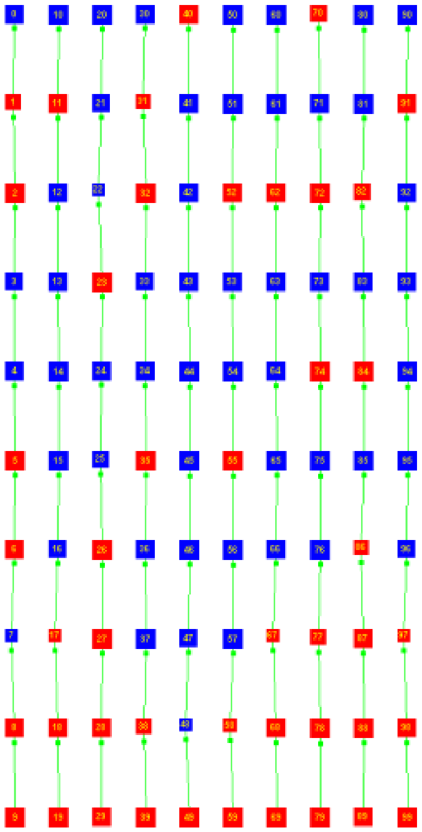
Fig. 8. Mean perceived economic success of maintainers and non-maintainers over time with the yield threshold set to 9.0, an decision bias of 1.0 and a mean yield memory capacity of 5 years with radius 2. The perceived economic success is normalised to the interval [0, 1] (cf. section 4.1).



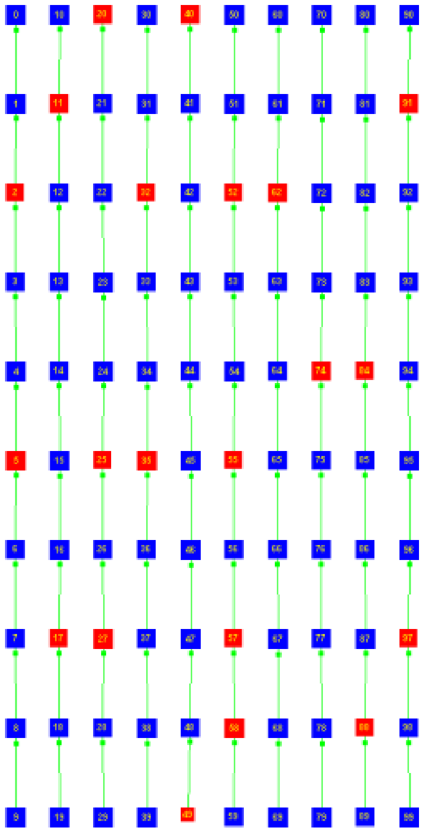
Year 3 (wet)



Year 4 (normal)



Year 14 (normal)



Year 33 (wet)

Fig. 9. Yields and LRS strategies on individual land parcels along ten channels (left to right) in year 3, 4, 14 and 33. Land parcels are represented as squares connected by green lines indicating the dependency relation (flow direction from top to bottom). The size of each square is proportional to the yield for the respective land parcel. Red squares indicate LRS neglect, blue squares LRS maintenance.

Scenario 3 – The combined influence of economic success and social support

In the third scenario, farmer agents use both their past economic success and the social influence of other agents as a basis for their decision making. We assume that all farmers balance economics and social support equally, i. e. the decision bias is set to 0.5 (neutral) for all agents. The WPI agent has a social influence level of 3 (i.e. it is three times as influential as a farmer agent).

The acquaintances network used in the simulation shown here has a scale-free network topology with an average node degree of 10. The assumption of a scale-free topology is supported by Odra case study narrative storylines and by many other studies on social networks (cf. Barabási 2002; Newman 2003). The scale-free network used in the simulations is generated by an algorithm described by Ebel, Davidsen and Bornholdt (2002). This algorithm allows generating a sufficient proxy of a scale-free network for 100 nodes and an average node degree of 10. As pointed out before the WPI is added to this network and linked directly to all farmers.

As the simulation starts out with no LRS maintainers, the general opinion dynamics between farmers initially generate high perceptions of social support against LRS. Since in addition the WPI agent's activity now influences the decision making of the farmer agents, opinions are slowly pushed towards LRS maintenance. Just as in the previous scenario, Figure 10 shows the proportion of farmers who change their opinion about LRS maintenance as an indicator of the system's volatility. Figure 11 compares strategy changes between the group of maintainers and the group of non-maintainers. Figure 12 shows the corresponding convergence of the number of LRS maintainers to a stable state of 100% after 26 years. Around year 16 the barrier of 50% LRS maintainers is breached which triggers an avalanche pro LRS. This is reflected in Figure 11 as a much higher opinion shift towards maintenance.

Figure 13 shows the resulting increase in the average of farmers' crop yields. Again, compared to the previous scenarios average crop yields increase and the deviation between farmers decreases.

Figure 14 contrasts the development of economic success and social support over time showing average values over the 100 agents. The perceived economic success starts off with unrealistically high values because agent yield memories are initialised with 5 (± 2) "good" years. The value falls as soon as agents experience the first years of the simulated weather sequence. When the shift in LRS strategies starts (see Figure 14, years 3 and 4) the average social support indicator falls steeply from around 86% to below 63%. These low values of social support persist throughout the phase of high volatility. As more and more agents switch to LRS maintenance social support rises again until year 26 when the WPI becomes passive (see Figure 14). In parallel to the social support the perceived economic success rises continuously. It has to be noted that with 100% LRS maintainers (and thus complete consensus on LRS) mean social support stabilises only at a level of 0.86. This is due to the normalisation of the farmers' social support perception which maps the maximum perceivable social support to 1.0 including possible influence exerted by the WPI. Accordingly, the perceived social support drops below 1 when the WPI becomes passive.

Figure 15 shows the development of the perceived economic success of maintainers and non maintainers. LRS maintainers start with very low economic success: this is what caused them to shift to maintenance. After that and similar to Figure 14 maintainers become more and more successful. Figure 16 contrasts the perceived social support of LRS maintainers and neglecters. As one would expect, during the phase of volatility, both economic success and social support are on very similar levels for both groups of agents.

Finally, Figure 17 displays the spatial distribution of opinion shifts along the ten channels over time. We show 4 snapshots for the years 3, 4, 14, and 33. The general dynamics is that agents start maintaining LRS from top to bottom. This reflects the perception that the topmost agents are in general more severely affected by flooding.

In scenario 3 it is assumed that in addition to appraising their economic success farmers also include the perceived social influence in their decision process. Once the WPI gets active it continuously pushes the opinion making process towards LRS. Figure 14 clearly shows that in the first phase of the volatile period (until year 17), economic factors dominate decision making, whereas in the second phase the perceived social support becomes the main driver. It seems to be this second phase of the decision dynamics that mobilises possible free-riders that were observed in scenario 2, to partake in the collective action.

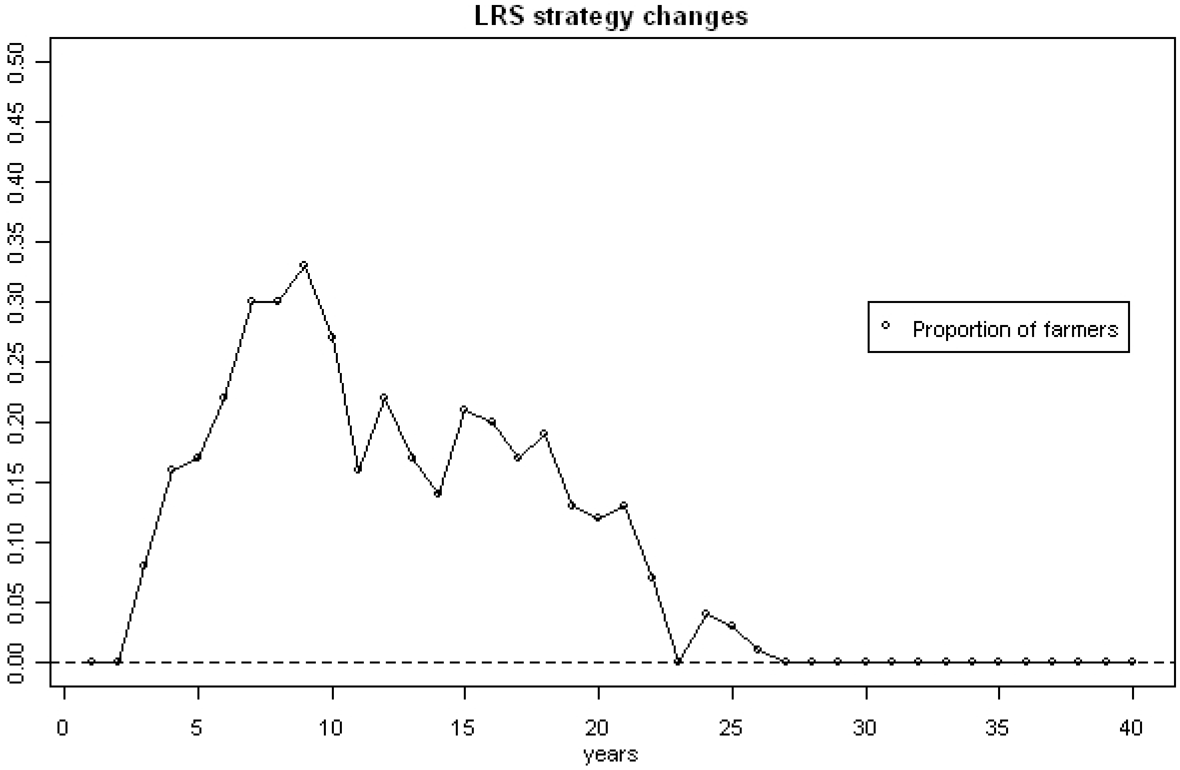


Fig. 10. Strategy changes over time as an indicator for volatility. Each dot marks the proportion of farmers who have switched their LRS strategy in one year. Note that the change can be either way, i.e. in favour of or against LRS maintenance.

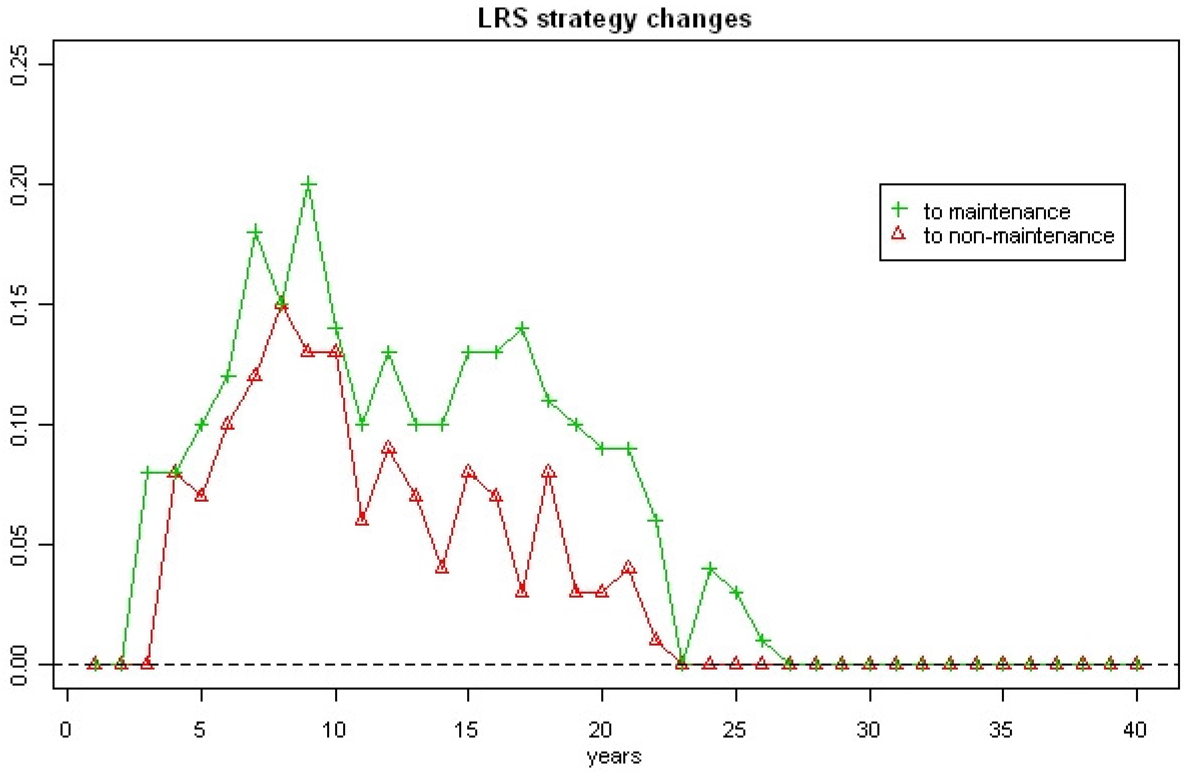


Fig. 11. Proportion of strategy changes to maintenance and to non-maintenance over time.

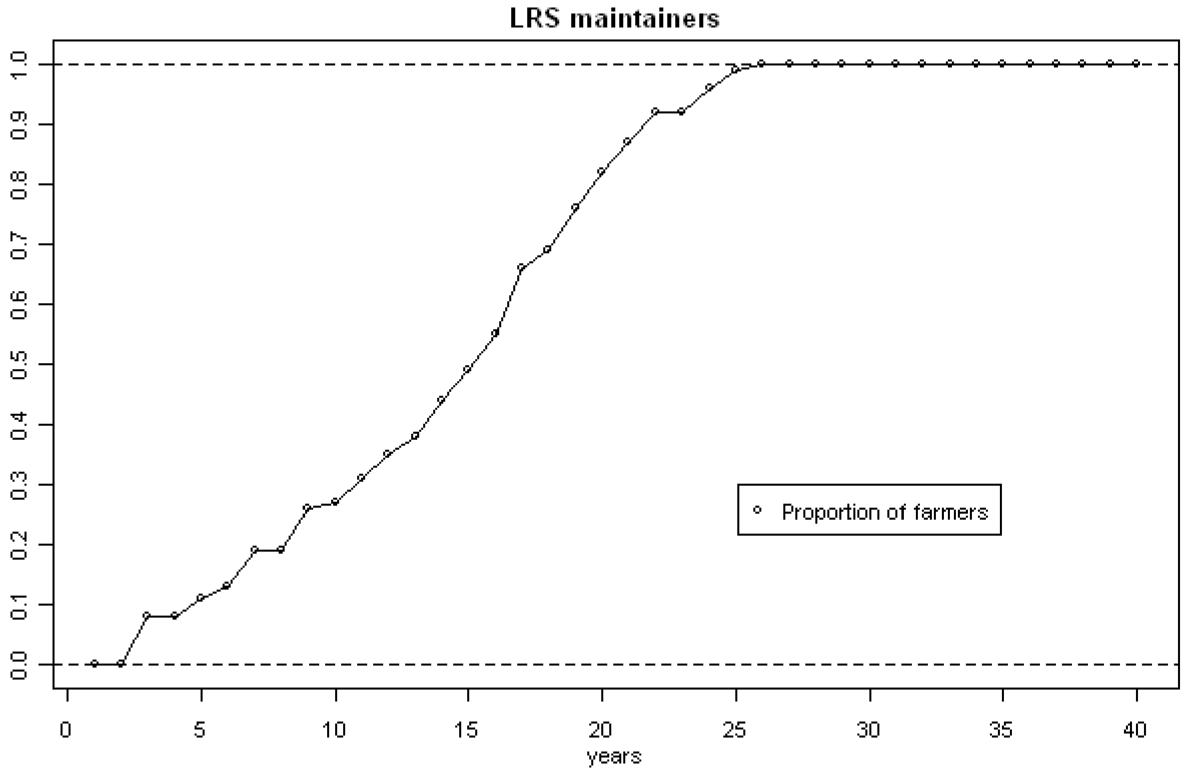


Fig. 12. Proportion of LRS maintaining farmers over time.

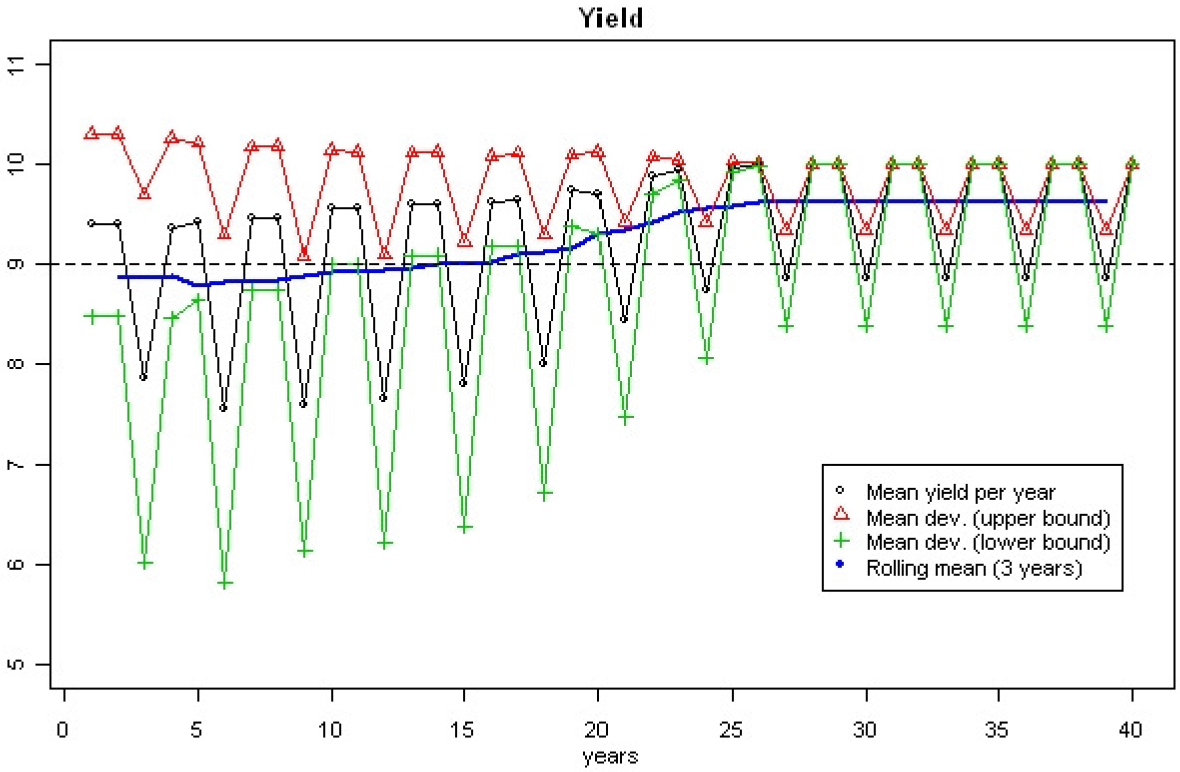


Fig. 13. Average yields of farmers over three years bounded by the mean deviation and the rolling mean.

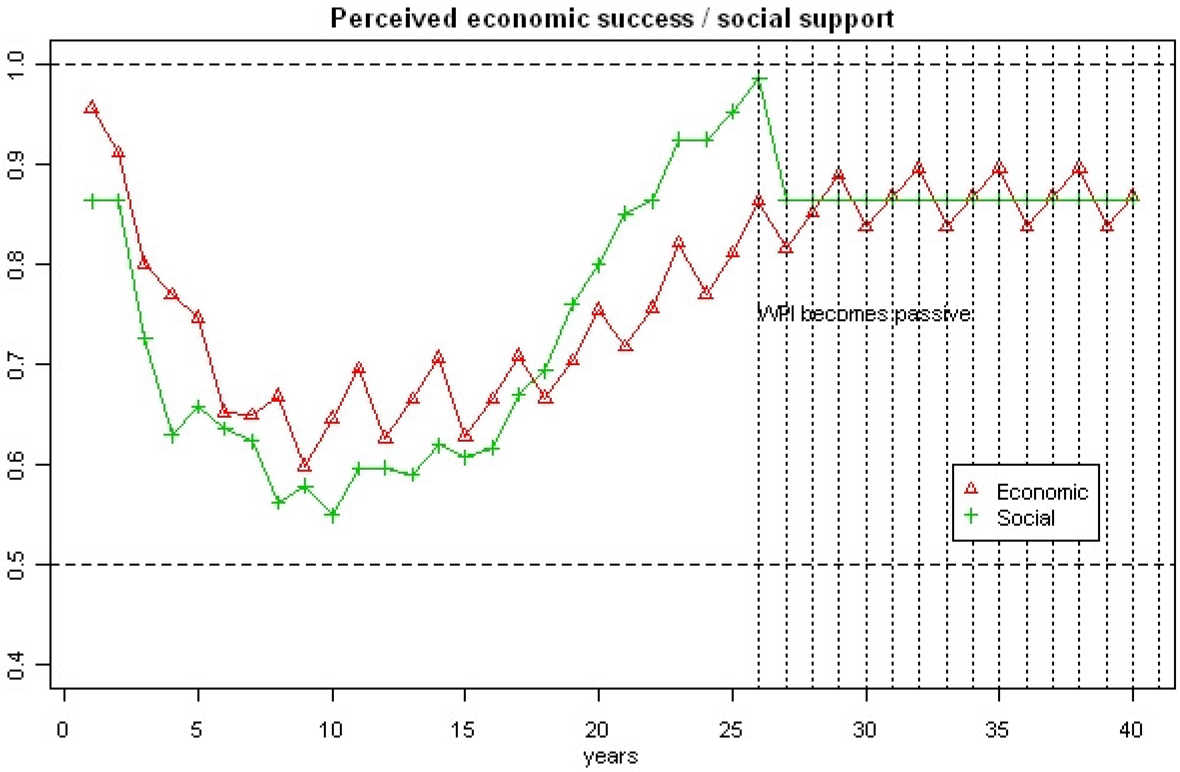


Fig. 14. Mean perceived economic success and mean perceived social support over time.

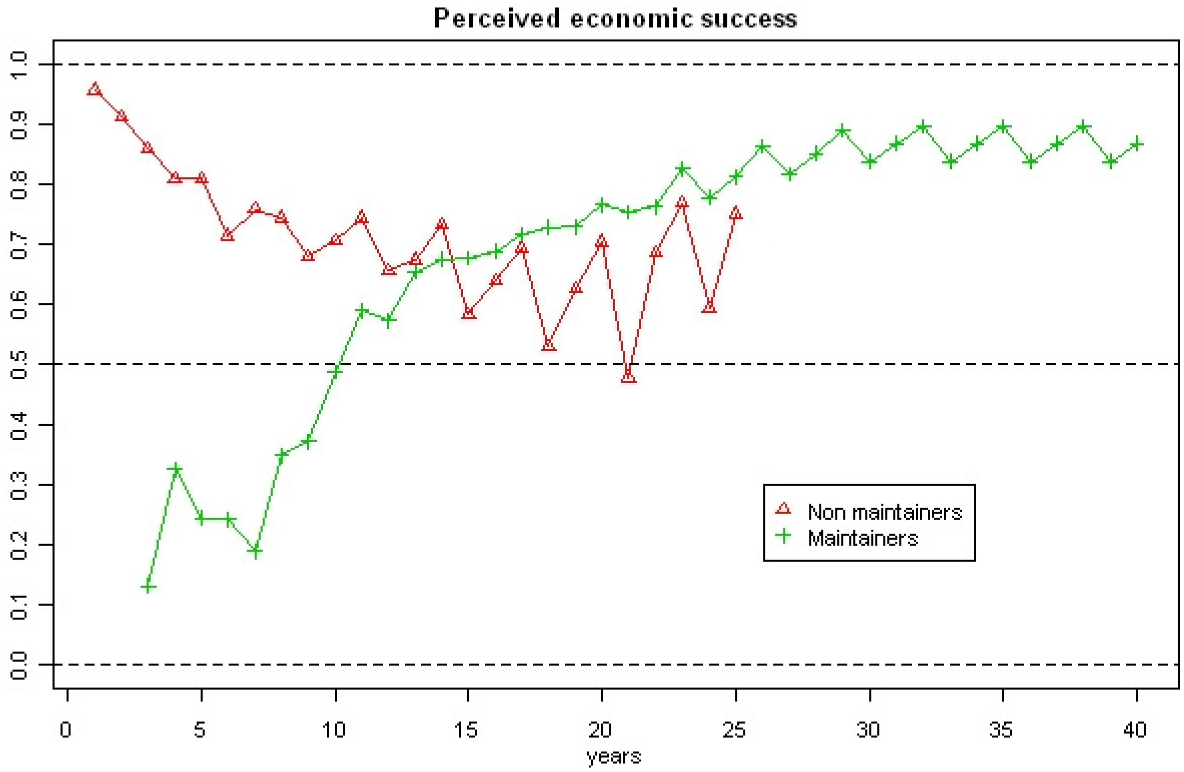


Fig. 15. Mean perceived economic success of maintainers and non-maintainers over time with the yield threshold set to 9.0, an economic sensitivity of 0.5 (i.e. neutral) and a mean yield memory capacity of 5 years with radius 2. The perceived economic success is normalised to the interval [0, 1]. Note that there are no maintainers left after year 26.

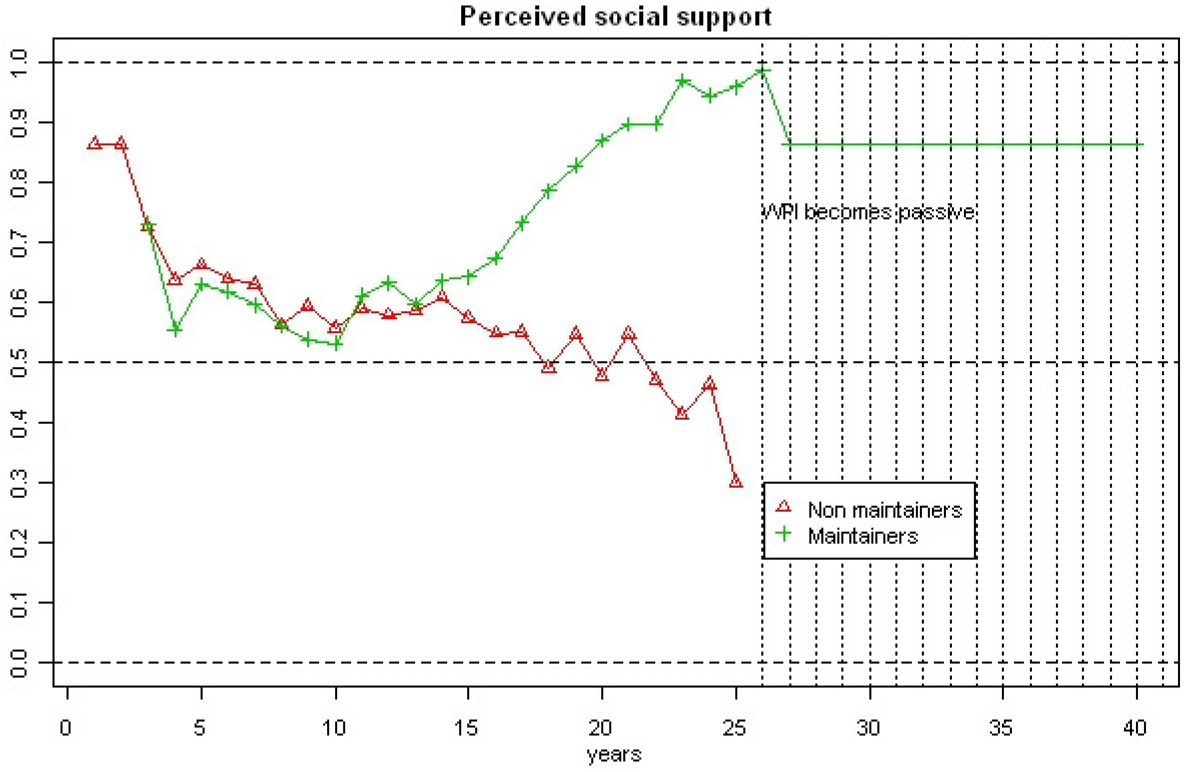
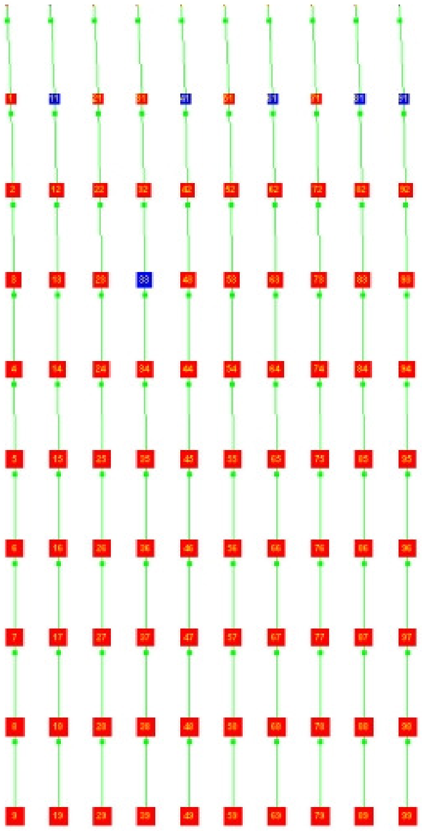
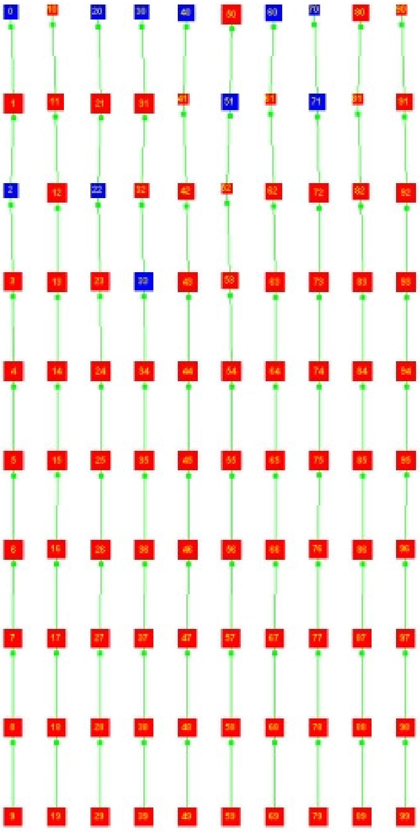


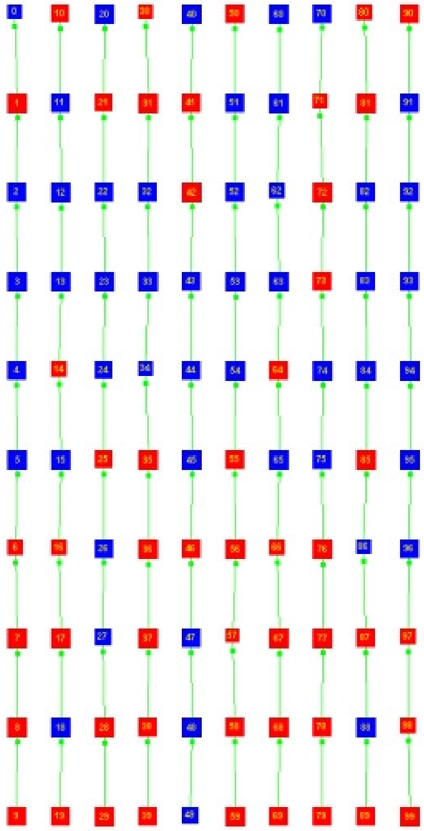
Fig. 16. Mean perceived social support of maintainers and non-maintainers over time with a social influence level of 1.0 for farmers and 3.0 for the WPI and an average acquaintance degree of 10. The perceived social support is normalised to the interval [0,1].



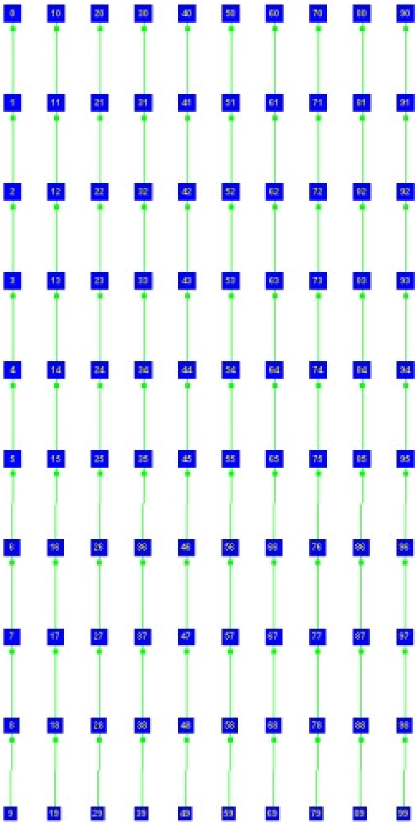
Year 3 (wet)



Year 4 (normal)



Year 14 (normal)



Year 33 (wet)

Fig. 17. Yields and LRS strategies on individual land parcels along ten channels (left to right) over time. Land parcels are represented as squares connected by green lines indicating the dependency relation (flow direction from top to bottom). The size of each square is proportional to the yield for the respective land parcel. Red squares indicate LRS neglect, blue squares LRS maintenance.

2.2.6 Discussion

The Kassel work group has engaged in a modelling process that starts out from evidence describing the particular situation characteristics of a case study. In a collaborative, iterative abstraction process with domain experts and stakeholders we identified the decision dynamics of farmers regarding the maintenance of a collectively managed land reclamation system as a sub-domain of the case study that is suspected to be understandable and interpretable in terms of complexity indicators, network characteristics, complex human-environmental interactions and basic theoretic or phenomenological structures, like social dilemmas.

The presented integrated model comprises an abstract biophysical model that reflects the main hydro-agricultural properties typically found in the case study area and a coupled agent-based model. The SoNARe agent-based model simulates the collective decision making of typical landowners in the target area under the fluctuating boundary conditions set by the biophysical model. Landowner decision dynamics are represented by actor types, stylised behavioural rules and well-founded psychological assumptions about social influence, memory capacity and social networks. While the model is being tested with only a small number of actors, it is easily scalable to several hundreds of actors without losing the basic environmental or social structure.

The presented scenario runs are extreme: The first scenario assumes passive actors that are not willing to partake in the collective action. This results in a high conflict potential between individual farmers caused by the significant inequality of the attained crop yields. The second scenario suggests that under the assumption of selfish farmers who only consider their individual farming success roughly a fifth of the farmers shows free-riding behaviour. This clearly demonstrates the social dilemma induced by the hydrological interdependencies of farmers' land parcels. Scenario 3 adds social influence to the decision process which results in the emergence of a positive social lock-in. Due to the water partnership initiator's activity and the subsequent economic success of LRS maintainers, a self-sustained water partnership can be installed in scenario 3.

The SoNARe model produces, besides other behavioural indices, a measure of volatility (the amount of strategy changes by the actors). When comparing the development of the volatility indicator in scenarios 2 and 3 (see Figures 5 and 10) one can observe that for scenario 2 the indicator has peaks to almost 0.4, whereas in scenario 3 the indicator is always well below 0.35. Furthermore, in scenario 3 the indicator drops to zero earlier than in scenario 2. As a conclusion, this might indicate that under the given circumstances the presence of an active social network and of mechanisms of social influence dampens phases of high volatility in opinion dynamics and instead leads to a coherence effect.

In spite of the situation's underlying dilemma structure prone to free riding, a social "activity seed" together with some social and economic pressure exerted on the participants is sufficient to trigger the installation of a working water partnership and to keep it alive. The intertwining of social and economic processes and their long-term effects will have to be investigated further. Still, it is safe to attribute some effectiveness to the modelled institution of the WP and the leading WPI. This result will be discussed with the local stakeholders of the case study.

2.2.7 Further Steps

One main task ahead is to continue the incorporation of evidence in the model. We are currently integrating available economic data on income, subsidies, LRS maintenance costs, allowances etc.

Moreover, the model is to be enhanced with a simple land market which allows small farmers to sell their land parcels to commercial farmers. This enhancement is important mainly in the two following respects: firstly, it enables us to study the effects of dynamics in the social network structure since small farmers may leave the social network when selling their property and secondly, since farmers must decide on whether to sell or buy land, we can show that our model of farmer decision making naturally extends to multiple decisions.

Both the abstract and the evidence-driven model versions will be investigated as regards parameter sensitivities and relevant indicators such as volatility and phase transitions. Investigations will start out from the three extreme scenarios discussed above and deal with transitions between the scenarios. We feel that scenario shifts in the model can be formulated as parameter changes along different “storylines”. It will be examined under which (social, economic, environmental) circumstances the passive scenario 1 shifts to the socially active scenario 3. Which circumstances inhibit or break-up a positive social lock-in, i.e. what triggers a transition from scenario 3 (back) to scenario 1?

2.2.8 Publications

The Kassel group has contributed a paper to the ESSA 2007 Conference. Also, a second paper which was written in collaboration with the CAVES project members Karolina Krolikowska and Gregorz Holdys and which covers more recent results has been submitted to the online journal JASSS.

2.2.9 References

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2.3 Macaulay Institute

2.3.1 Introduction

We are in the process of constructing models of the development of rural land use in Upper Deeside and surrounding areas of the Grampian region, between the mid 1980s and 2030. Models of the period up to the present are intended to determine how far our modelling approach can replicate the course of land use change (and farm size change, so far as we are able to obtain data on this), given the major external shocks and stresses impinging on the land use system over that period. Models of the period from the present to 2030 are intended to be relevant to climate change policy issues.

The work of the CAVES Macaulay Modelling Team over the last six months can be divided into the following areas:

- Use of FEARLUS 0-8-2-1
- Development and use of FEARLUS 1-0-1
- Data collection
- Development of FEARLUS 1-1
- Design of a testing plan for FEARLUS 1-1
- Publications

For stakeholder validation work relevant to FEARLUS, see the Grampian case study report.

2.3.2 Use of FEARLUS 0-8-2-1

Work with FEARLUS 0-8-2-1 described in the report for March 2007 was continued, and has resulted in a conference paper (Gotts and Polhill 2007). A FEARLUS 0-8-2-1 model was used with a variety of parameter settings to investigate the feasibility of combining collective rewards with social interactions in the control of diffuse agricultural pollution. The approach modelled involved mutual monitoring of the production of pollutants by neighbours, among a group of farmers offered a collective reward by a "Government Agent" if measured levels of the pollution they produce between them are satisfactory. For phosphate or other water pollution, this would need to involve the farmers in a river catchment or sub-catchment, pollution levels being measured just downstream of the furthest downstream farms. However, the model is sufficiently general to be applied to airborne pollutants or greenhouse gases, if levels of these can be measured only, or at lower cost, over an area containing multiple farms.

FEARLUS agents representing farmers ("Land Managers") have preferences which cannot be reduced to a single measure of "utility". The Land Manager agents in the simulations in which the Government Agent pays a reward if total pollution is below a threshold face a form of social dilemma, if they are considered as profit maximisers: each individually will generally be better off if they adopt the land uses with high pollution intensity, as these also have high mean profitability (although profitability of any land use varies from year to year and from parcel to parcel); but if all (or enough) do this, the reward will not be paid. There is abundant empirical evidence that people often act more cooperatively than if they were rational profit maximisers in such situations; and that this is more likely to occur if there is or has been social contact between those involved. In the context of farming Burton (2004) describes how farmers are influenced by their desire to be seen as a "good farmer" by their peers. Hence our Land Managers have the capacity to "care" about their neighbours' approval or disapproval, as well as about their income. However, the relative importance given to the two factors can vary from year to year, changes being prompted by specific events – in the FEARLUS 0-8-2-1 model used these were a bad harvest, or a specified degree of unpopularity in the preceding year. While we cannot cite specific empirical support for such a "salience" effect, it is intuitively plausible that in weighing very different types of benefits and costs (concerning income and peer approval), farmers are influenced by recent events drawing their attention to one factor or the other. Land Managers tended to disapprove of high-polluting neighbours (this could be interpreted either as intrinsic disapproval of the pollution, or in the runs where a conditional collective reward was on offer, disapproval of those threatening achievement of that reward).

The parameter settings used in different runs allowed us to examine the consequences (in terms of pollution levels and other effects) of providing a collective reward of various sizes and subject to different allowable pollution thresholds (or no such reward), in combination with a range of assumptions about how farmers might react to their neighbours' production of pollution (including a condition where they did not react to it at all). The (provisional) conclusions of the work were as follows:

3. Mean pollution levels were almost always above the reward threshold, but a range of thresholds nonetheless reduced this mean level, under a range of algorithms for Land Managers'decision making.
4. Overall means and means of maximum pollution levels showed very similar patterns (possible exception: the Dis-D class under less effective reward schemes).
5. As would be expected, increasing the collective reward increased the effect.
6. Varying relative profitability of Land Uses gave opportunities for Land Managers took longer to learn that cutting pollution can pay. When the pollution threshold was set too low (although at an achievable level), this took longer.
7. If Land Managers cared about their neighbours opinions (and disapproved of their neighbours polluting), pollution was lower.
8. The way social pressure to reduce pollution was implemented made some difference, but not much.
9. Effects 4 and 5 together had a larger effect than either acting separately.
10. The general pattern of a simulation run in which the reward had a marked effect was of considerable variation in pollution levels as exogenous factors made different land uses more or less profitable; but levels much above the threshold were seldom maintained for long periods.
11. The availability of the collective reward reduced volatility both in land use and in land ownership: in land use because the proportion of the time Land Managers were satisfied with their income increased; in lland owership because the extra cash being pumped into the system reduced the number of bankruptcies.

Figures 1-3 illustrate these effects. "NoSAF" stands for "No Social Approval Function" – i.e., neighbours neither approved nor disapproved of each other; “Dis-D” is one of the Social Approval Functions used (the others had similar effects). Thus in each figure, the top two subfigures show output from runs with no collective reward, the bottom two from runs with a polution threshold of 2000 (pollution) units and a reward of 50 (monetary) units per parcel managed. The left two subfigures show output from runs without social (dis0approval interactions, the right two subfigures from runs with such interaction.

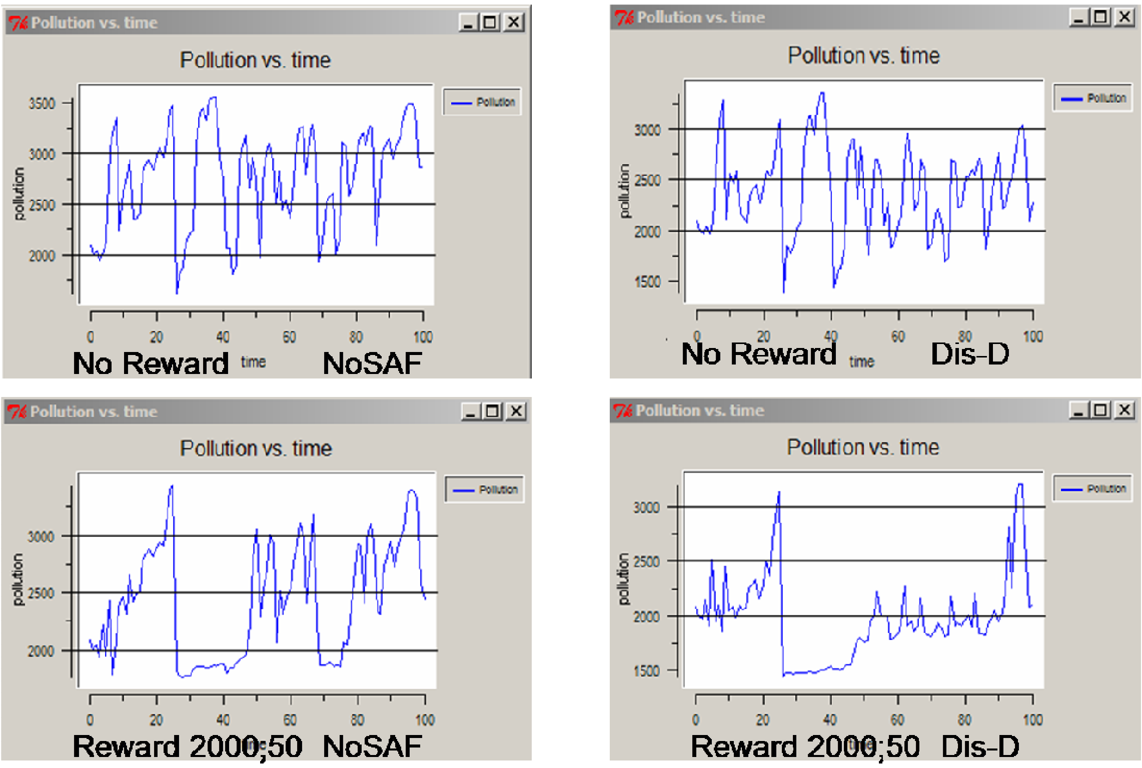


Figure 1: Pollution levels in four example runs of FEARLUS 0-8-2-1 model.

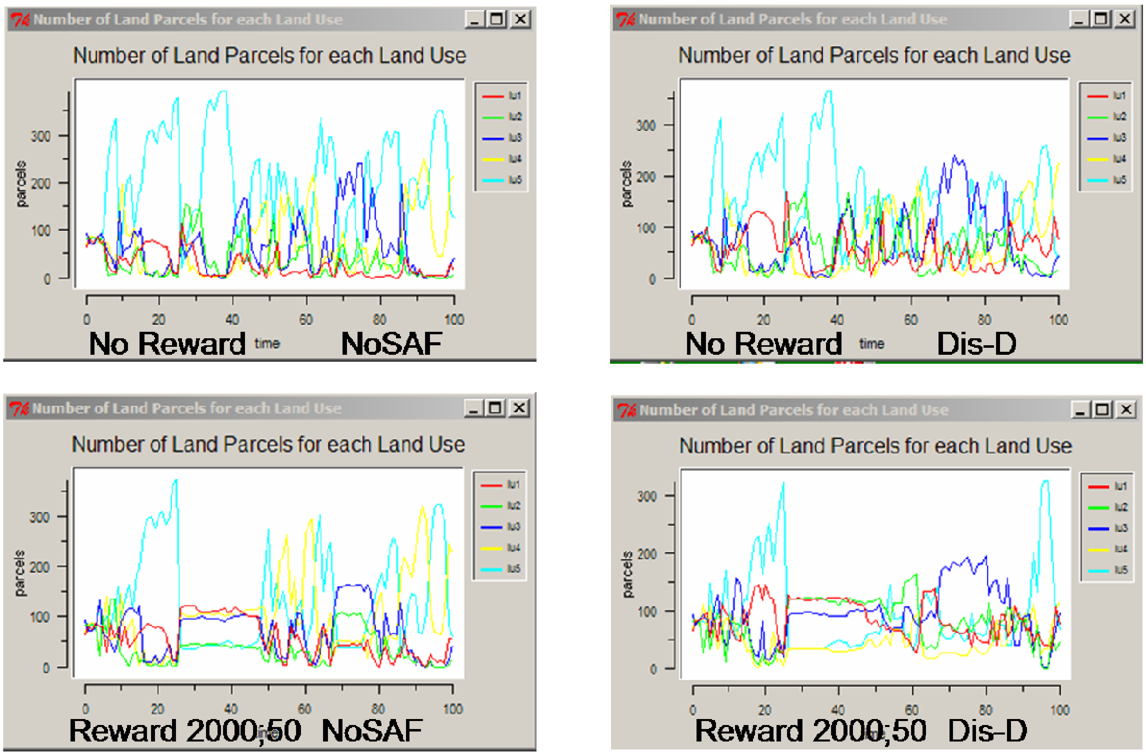


Figure 2: Change in land uses over time in four example runs of FEARLUS 0-8-2-1 model.

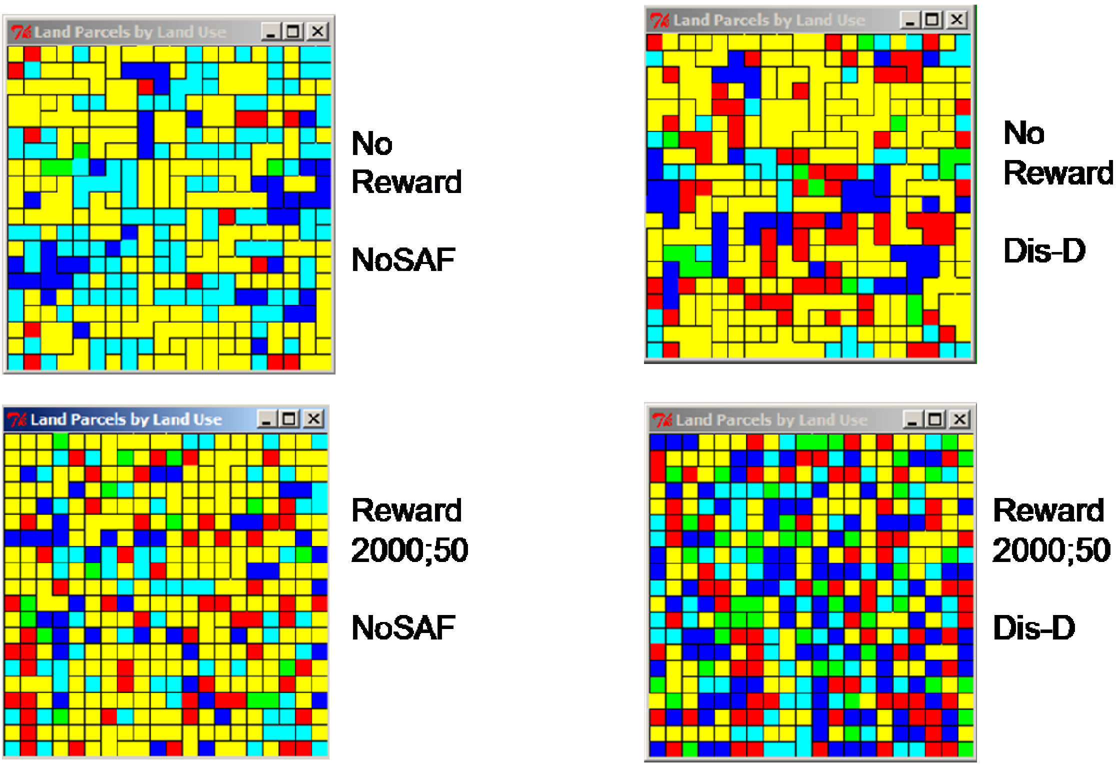


Figure 3: Land ownership after 100 years in four example runs of FEARLUS 0-8-2-1 model.

2.3.3 Development and Use of FEARLUS 1-0-1

In comparison to FEARLUS 0-8-2-1, FEARLUS 1-0 (release of which was reported in the previous six month report) had the following additional features designed to increase its realism (alongside others added for other purposes):

- Use of lookup tables to calculate per-parcel yields from land uses, and the resulting gross economic return, in place of bitstring matching. These tables make it possible to specify climatic and local biophysical effects on yields, and the effects of economic factors on gross economic returns, in a far more realistic, flexible and comprehensible way.
- Use of an endogenous land market model (ELMM) involving sealed bid auctions in place of a mechanism by which all parcels had a fixed (and equal) price.
- Methods to implement economies of scale via a farm-scale fixed costs parameter, which can be made to vary over time, and parameters that reduce overheads in proportion to area of land assigned to a particular land use. Note that the approach taken can also be employed to represent the fact that different land uses have different costs even when both are applied to the same amount of land; and indeed this has been its primary use thus far.
- Provision for land managers to have off-farm income sources.
- Augmentation of Case Based Reasoning decision making agents with the possibility to use imitative and other experimentation strategies when aspiration thresholds are not met.

FEARLUS 0-8-2-1 and FEARLUS 1-0 both have Land Managers who base their decisions on a balance of desire for profit and for their neighbours' approval. However, consideration of the work carried out with FEARLUS 0-8-2-1, and discussions of the details of FEARLUS 1-0 in this area prompted some changes, to produce FEARLUS 1-0-1 (maintaining , however, backward compatibility with FEARLUS 1-0). The provisions for dual-criterion land use selection used in the FEARLUS 1-0-1 runs reported below are as follows:

- A Land Manager has aspiration levels both for profit, and for the approval of their neighbours.
    - The aspiration for profit is set at a whole-farm level, and is proportional to the size of the farm.
    - The aspiration for neighbours' approval is a numerical "mean value" of approval of the Land Manager from those neighbours of whom the Land Manager does not disapprove. In the work described below, the only approval values used were 1 (approval) and -1 (disapproval), but there is provision for a wider range of values to be employed.
- If both these aspiration levels are met at the turn of the year, all land uses remain as in the preceding year.
- If either or both of the aspiration levels is not met, each land parcel's land use is considered in turn, using case-based reasoning as in FEARLUS 0-8-2-1. However, the events changing the relative importance (salience) of profit and neighbours' approval in FEARLUS 0-8-2-1 were replaced:
    - The salience of profit is increased when (and currently, only when) the Land Manager makes a net loss in a particular year.
    - The salience of neighbours' approval is increased when (and currently, only when) a given proportion of all the Land Manager's neighbours disapproved of them. (The rationale for considering all neighbours in this context, but only neighbours of whom one does not disapprove when applying the neighbour approval threshold is psychological: that the approval of those we assess positiviely is what matters to us

most, but a high level of disapproval even from those we ourselves despise is likely to increase the importnace of approval from those whose opinions we value.)

In addition, the precise grounds on which one Land Manager approves or disapproves of another were also changed. In FEARLUS 0-8-2-1, the possibilities were that a Land Manager would approve of those using only low pollution land uses and disapprove of those with high mean pollution per unit area levels; or that they would approve of those with lower mean pollution per unit area than themselves and disapprove of those with higher. On consideration, these were both felt to be unrealistic, implying that farmers can indeed assess the mean pollution per unit area, and a simpler possibility was added, and used in all the runs described below: that Land Managers disapprove of those neighbours using (on any parcel) any land use more polluting than any they are currently using themselves; and approve of all other neighbours.

Work with FEARLUS 1-0-1 has focused on developing a "semi-realistic" model of land use and greenhouse gas production in Upper Deeside. By "semi-realistic" we mean that the land uses (or more precisely land management strategies) employed are similar to those employed in Upper Deeside, the yields and net economic returns from those strategies under a range of conditions are at least qualitatively plausible, and the physical environment used is (for some model runs) based on maps taken from the UK Agricultural Census. It is considered that ensuring that such a semi-realistic model gives plausible outputs is a necessary stage in adapting an originally abstract land use model for use in a specific geographical and socio-economic context.

Since by far the predominant category of agricultural land use in the area is the raising of ruminants (cattle and sheep) primarily for meat, the "land uses" in the semi-realistic model are simply different variants of this. The most important agricultural sources of greenhouse gases are ruminants, which produce methane as a byproduct of digestion, and nitrous oxide, a byproduct of nitrate fertiliser application – both can be assumed to increase with greater stocking densities of ruminants. Eight variants of ruminant production are used in the semi-realistic models developed thus far, differing in stocking density (very low, low, medium or high), and use of bought-in feed (present or absent – this is assumed not to make a significant difference to net greenhouse gas production). Sheep and cattle are not currently distinguished: in fact, data from interviews and the agricultural census indicate that cattle are kept on the better land (hence at higher densities), sheep on the poorer. Climate is classified only as clement, moderate or inclement, and is changeable from year to year, but temporally auto-correlated. Land is similarly categorised simply as good, intermediate or poor; three different distributions of this land have been experimented with:

1. A "patchy" distribution. Equal proportions of good, intermediate and poor land, with pairs of neighbouring patches more likely to be of the same quality than randomly chosen pairs, but not greatly so.

2. A "three stripes" distribution. Equal proportions of good, intermediate and poor land, in three broad stripes.

3. A "semi-realistic" distribution. Based on UK Agricultural Census data at 1km2 resolution. "Good" land is taken to be that classified in the census as "agricultural land, Scotland", "intermediate" land that classified as "woodland", and "poor" land that classified as upland or "restricted agricultural land". The identification of "woodland" as "intermediate" requires explanation: data on cattle shows that they are kept in "woodland", indicating that these squares are in fact only partially wooded.

The higher stocking densities provide higher yields on good land and in clement climatic conditions, but also have higher costs, higher pollution production, and greater dependence on good land and clement climatic conditions. Input and output prices can vary independently, with the result that use of bought-in feed pays off in some years, but not others – as with climate, economic conditions vary, but show temporal auto-correlation. The result is that the most profitable "land use" varies both across land parcels and across years, but on good or intermediate land, one of the relatively high-pollution land uses is generally the most profitable. In line with findings from interviews concerning the great reluctance of farmers to relinquish their land, land parcels are put up for sale only when a Land Manager leaves the simulation (and currently, this happens only when they go bankrupt).

Thus far, two phases of work have been undertaken with FEARLUS 1-0-1:

1. A semi-systematic search through parameter space to find parameter values which produce intuitively reasonable results with neither a reward scheme nor social approval/disapproval in operation. By "reasonable results", we mean for example that Land Managers are able to remain in business, but do not make money every year, and would go out of business if they persistently made poor decisions; that new entrants are able to buy land parcels, but do not always outbid existing Land Managers; and that the land uses chosen correspond reasonably well (but not perfectly, since climatic and economic conditions vary from year to year and have to be tracked) to those that would be most profitable. The parameters varied in this semi-systematic search included the overall difficulty of making a profit (defined by a "break even threshold" specifying the gross economic return necessary to break even when using the most costly land use), proportions by which this threshold is reduced for the remaining land uses, relative yields (on different qualities of land) of the various land uses, and the amount bid by prospective new entrants for land parcels put up for sale after a bankruptcy. The search has produced a set of parameter values suitable as a starting point for further exploration of the parameter space, including a sensitivity analysis. However, there are at least two features of the resulting outputs that are not entirely satisfactory:
    - Particularly when the "patchy" environment is used, the assignment of land uses to land parcels is less stable, and perhaps less profitable, than might be expected.
    - Possibly as a consequence, levels of bankruptcy are higher than is plausible (at around 20%-25% of Land Managers per annum). However, the initial runs with FEARLUS 1-1 (see section 6) suggest that more plausible levels can be achieved by giving large farms an advantage over small ones in terms of running costs – which has the advantage of economic plausibility.
2. Using the set of parameter values produced by phase 1, check whether the findings of work with FEARLUS 0-8-2-1 remain the same. It appears that the most basic findings do: both offering a collective reward, and instituting social approval/disapproval interactions between neighbours appear to reduce pollution levels when applied separately, and when both are applied together, the reduction is greater than either produces alone. The effect of the collective reward in decreasing volatility also appears to have been maintained; the remaining preliminary findings from section 2 have not yet been checked.

Since FEARLUS 1-1 is now operational, further work will take place using that version of the modelling software.

2.3.4 Data collection

With regard to land use in Upper Deeside, an analysis of additional sources of information on the Upper Deeside test site has been compiled by Lee-Ann Sutherland. This will be used to supplement the information derivable from the UK Agricultural Census discussed in the previous six month report.

It was noted in the previous six month report that price series were required. The best available agricultural price series for our purposes appear to be those produced by DEFRA (Department of Environment, Food and Rural Affairs) at UK level. These cover the period from 1980-2005 at a level of detail that should be quite adequate for our purposes.

The main remaining gap in the input data necessary for fully realistic models concerns the effect of land type and climatic conditions on yields; since it is clear that we will be concentrating on meat yield from ruminants, it is not thought this will prove too difficult to obtain reasonable values for entry into the final lookup tables.

2.3.5 Development of FEARLUS 1-1

There are two main modifications to FEARLUS 1-0-1 to make FEARLUS 1-1 as it currently stands. One, of less direct relevance to CAVES, is the incorporation of a species metapopulation model (SPOM: Stochastic Patch Occupancy Model) into the FEARLUS codebase allowing the possibility to explore the impact of land use change on species composition at the landscape scale. The other consists of modifications to the Case-Based Reasoning algorithm to bound the size of the Episodic Memory and to allow the exchange of Cases between Land Managers in an 'advice network'. (The Episodic Memory is a database of a Land Manager's experience, consisting of a series of Cases, each comprising a State of the world in which the Case occurred (Climate, Economy, Land Parcel), a Decision (Land Use choice) and an Outcome (Profit earned and Social Approval attained).)

In FEARLUS 1-0-1, the Case-Based Reasoning algorithm had an Episodic Memory of unbounded size. Besides issues of computational efficiency and scalability of the model, this was also contrary to empirical evidence: people are known to have a limited capacity for remembering episodes. Indeed, research in expert systems found that most vocational expertise could be summarised in a rule-base consisting of the order of 1000 rules. In FEARLUS 1-1, two optional bounds can be placed on the Episodic Memory: (i) Cases can be given a limited time span. This was added on the suggestion of the field-researcher, who pointed out that succession on the farm means that even within enterprise, episodes older than 50 years would most likely not be considered during the course of strategic farm decision-making. (ii) The Episodic Memory itself can be given a limited size. These bounds are not unrelated. Land Managers in FEARLUS accrue Cases into their Case Base at the rate of one per Land Parcel owned per Year. A time limit on the Episodic Memory bounds the size of the Case Base to the Estate Size (number of Land Parcels) multiplied by the time limit. The size limit does not impose any direct bounds on the time limit, except in certain special circumstances. Although all Cases added in a particular Year will cause other Cases to be removed if the Episodic Memory is at maximum capacity, the Cases are selected for removal on the basis of their relevance to recent decision-making processes.

The algorithm for eliminating Cases from the Episodic Memory works thus:

- During consultations of the Case Base for decision-making process, a note is kept of those Cases that are a poorer match for the Expected State of the world than the current best-matching Case. These Cases are tagged as 'forgettable'.
- During the learning phase, the following two actions are taken to reduce the size of the Case Base:
    - If a Case time-limit has been imposed, then all Cases older than the time limit are removed from the Case Base (regardless of whether or not they are 'forgettable').
    - When adding new Cases for the Year to the Case Base, if a size-limit has been imposed, then the list of forgettable Cases is sorted in ascending order of the number of times the Case has been a best-matching Case during decision-making. For each addition to the Case Base that would exceed the size limit, another Case is removed from the front of the list of forgettable Cases. (This process does bias against newer cases, but ensures that important Cases are retained.)
- Before any decisions are taken in the subsequent Year, all Cases tagged as 'forgettable' have the tag removed.

To compensate Land Managers for the loss of their unbounded Case Base, and to introduce another layer of networking in FEARLUS, Land Managers may consult each other for advice when making Land Use decisions. This action is taken when their own Case Base fails to find a Case for a particular State of the world and Decision. Land Managers then use an Advice Strategy to create an ordered list of Land Managers to consult for advice. Land Managers giving advice then consult their Case Base, and return the best matching Case, if one can be found. Land Managers will not give advice to those they disapprove of, or who have disapproved of them (in either case, in the most recent Year only). Land Managers asking for advice use the Outcome of the first non-null Case returned by a Manager on their consultation list as a basis for selecting a Land Use. (An alternative approach would be to find the best matching Case from those returned by all Land Managers on the consultation list.) In this preliminary version of FEARLUS 1-1, two Advice Strategies have been implemented, one that consults all Land Managers in the Social Neighbourhood, another that consults all Land Managers belonging to the same Subpopulation in the Social Neighbourhood.

Using FEARLUS's prototype ontology-generating feature (Polhill & Gotts, 2007), the network structure can be imported into ontology viewing software such as Protégé, and then visualised using ontology visualisation tools such as OntoViz. This allows us to see the multi-layered network as well as its individual components, as illustrated in the following figures:

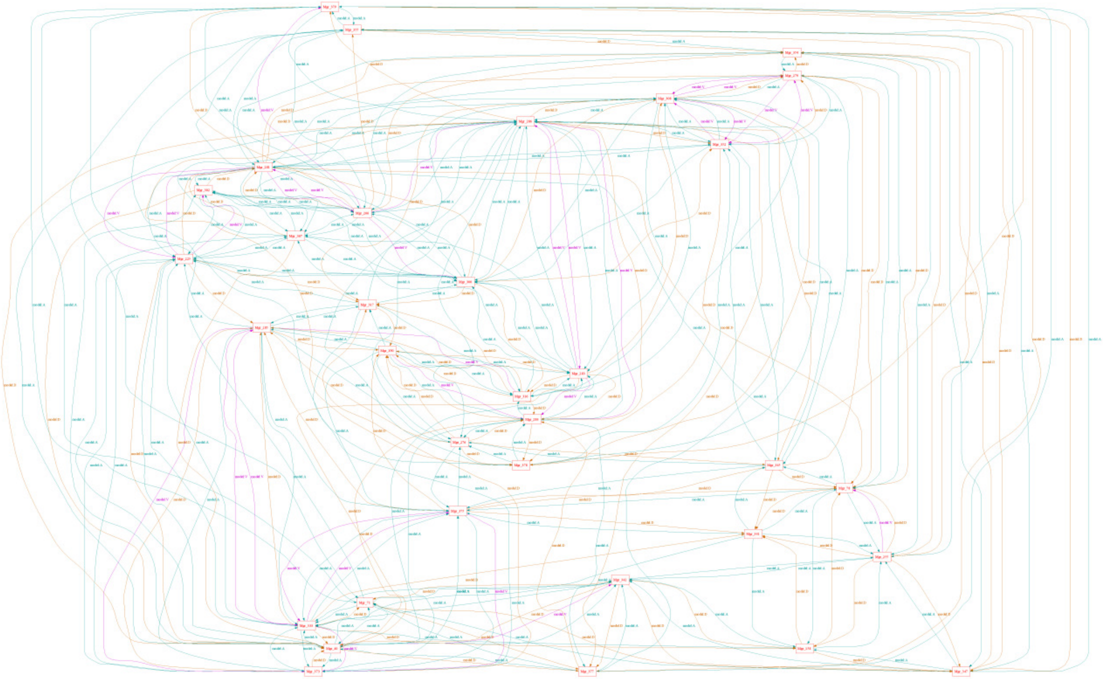


Figure 4: Advice, Disapproval and Approval networks from a run of FEARLUS 1-1

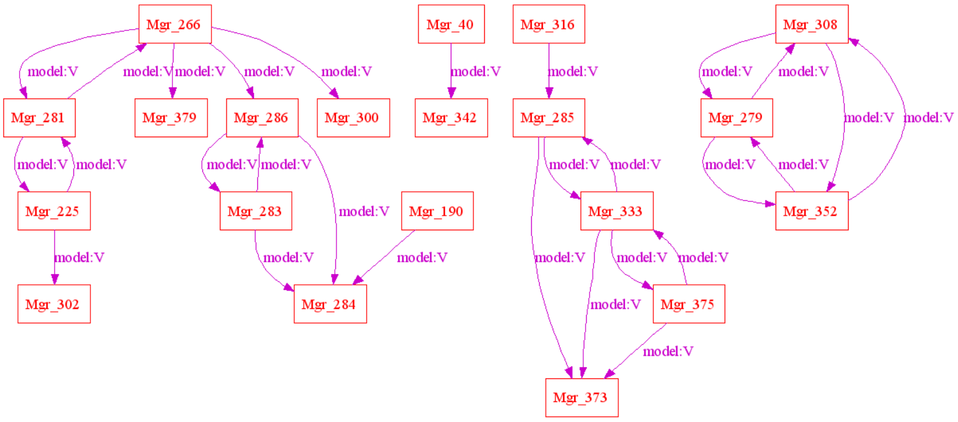


Figure 5: Just the Advice network

Figure 6: Just the Disapproval network

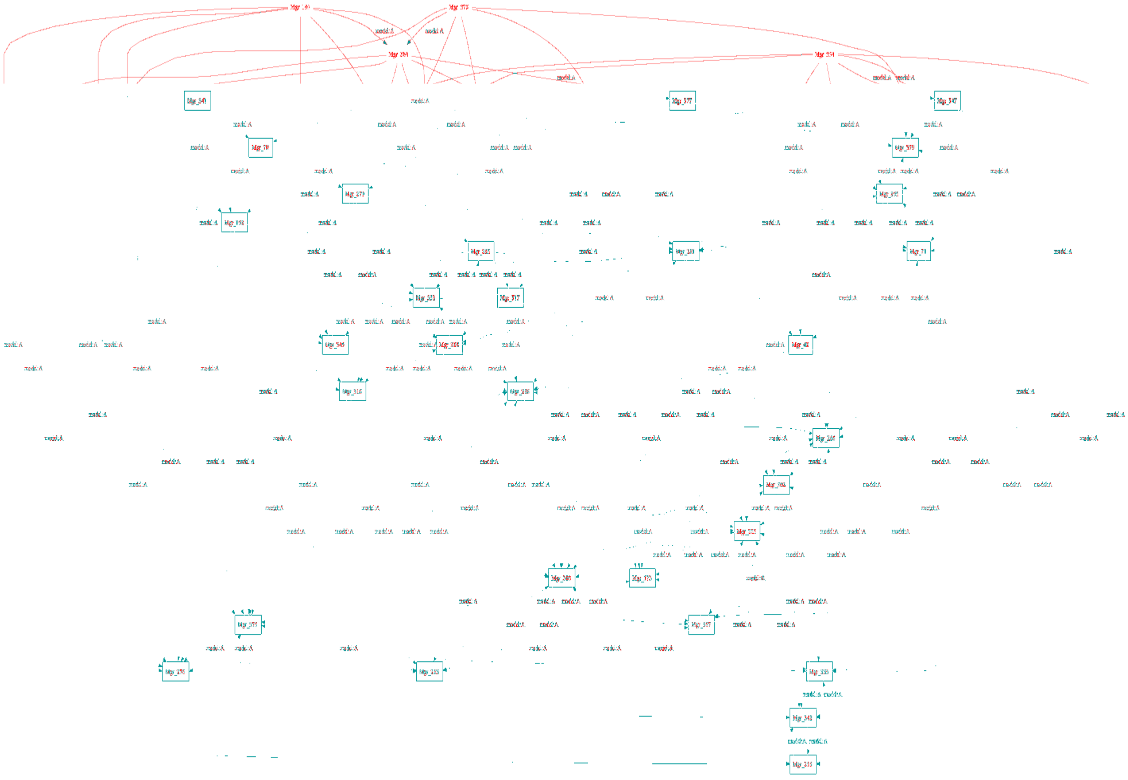
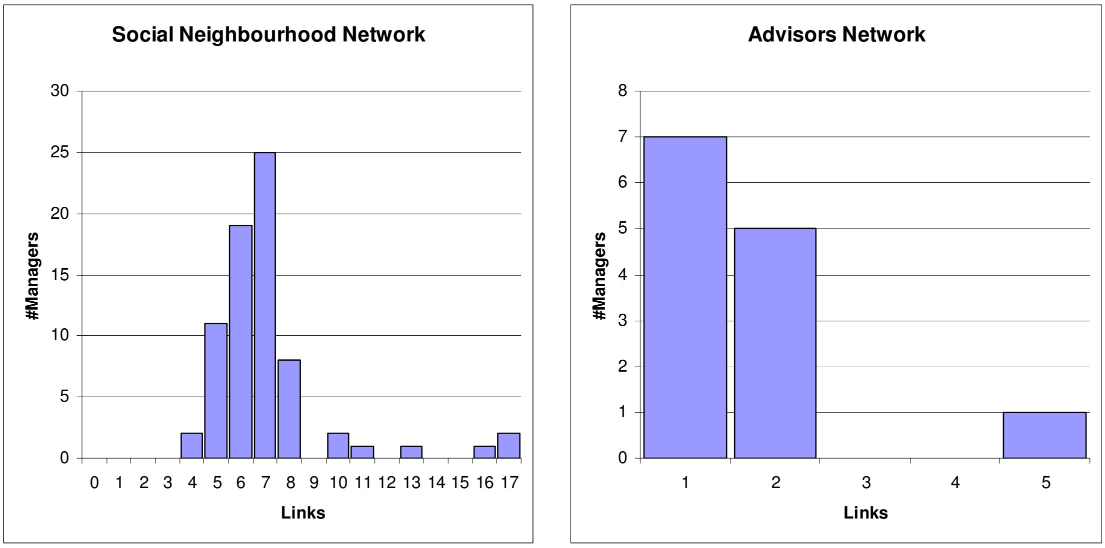


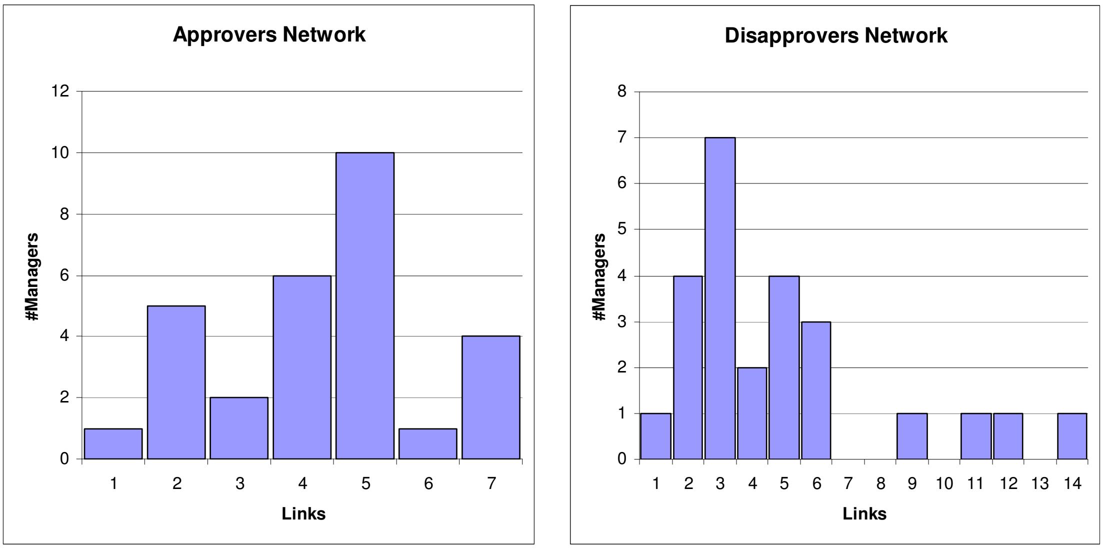
Figure 7: Just the Approval network

In addition, reporting facilities have been added to FEARLUS 1-1 to provide data for histograms for various layers of networks to be created (who sold a land parcel to whom, who is a social neighbour of whom, who approved/disapproved of whom, who was approved/disapproved of by whom, who received advice from whom). Some examples are given below:



Who is the social neighbour of whom *Who received advice from whom*

Figure 8: Social neighbour and advice network degree distributions



Who was approved of by whom *Who was disapproved of by whom*

Figure 9: Approval and disapproval network degree distributions

Some preliminary work has examined the effect of Advice on the total number of Bankruptcies (over 10 runs and 100 Years) as the size of the Case Base increases. Results at the time of writing are depicted below, which suggest the relationship is complicated enough that more runs are needed for a clear picture:

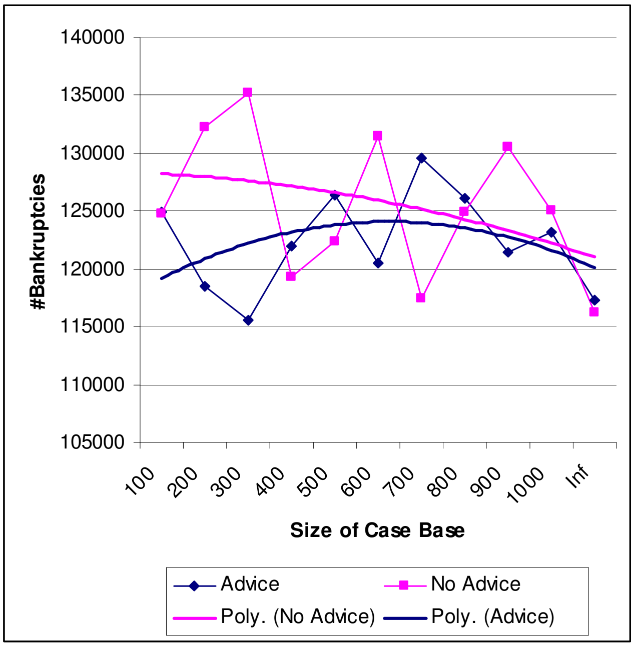


Figure 10: Preliminary results exploring the effect of Advice

It is worth noting that with the addition of the capabilities for requesting and giving advice, FEARLUS 1-1 models can now include four kinds of interaction between neighbouring Land Managers:

- The ELMM land market
- Imitation of land uses employed by neighbours (this can be used as an alternative to CBR, and an individual Land Manager may use both in the same year).
- Social approval and disapproval.
- Requesting and giving advice.

The operation of ELMM determines changes in the topology of the network of neighbours, which in turn limits the possibilities for buying and selling, imitation, social approval and disapproval, and giving and requesting advice. Since advice is only given if neither party disapproves of the other, there is a further connection between these two types of interaction; this would be expected to give some advantage in decision-making to those who are not disapproved of by their neighbours. Both advice-taking and imitation will affect the quality of land use decision-making, and can thus have indirect effects on the operation of ELMM. FEARLUS 1-1 thus includes a number of distinct but interacting networks.

2.3.6 Design of a testing plan for FEARLUS 1-1

Although successive versions of FEARLUS have proved robust in use, no systematic testing programme has been undertaken during the period of CAVES thus far. A testing plan has now been prepared, and will be applied to FEARLUS 1-1 as soon as some testing scripts have been written. Any errors uncovered will be corrected as part of the final CAVES upgrade to FEARLUS 1-2.

2.3.7 Publications

One refereeed journal article (Gotts 2007) and two conference papers (Polhill and Gotts 2007, Gotts and Polhill 2007) drawing on work within CAVES have been published in the past six months, and will be linked from the CAVES CVS server.

2.3.8 Work for the remaining period of CAVES

The main modelling activities over the next six months will be:

1. Complete the coding, documentation and testing of the final version of FEARLUS for CAVES modelling, FEARLUS 1-2. This will include a number of relatively minor changes from FEARLUS 1-1, including:
    - An option to allow the CBR algorithm for selecting the best-matching case to make direct use of biophysical similarity of land parcels rather than relying, as now, on spatial proximity as a proxy. It is though this may improve the algorithm's performance.
    - An option to allow for Land Managers to leave the simulation and sell up even though not bankrupt (with a certain annual probability, perhaps inversley related to farm profitability). This reflects reality, and should allow some turnover of Land Managers and changes in farm size without implausible levels of bankruptcy occurrence.
    - If a sufficiently simple way of modifying FEARLUS 1-1 can be found, a distinction between owned and tenanted land. The absence of such a distinction is probably the single feature which would most enhance FEARLUS's realism, but this advantage must be weighed against the time necessary to code and test any change.
2. Produce a final Grampian case study ontology. This will be produced by adding to the existing upper-level ontology concepts and relations derived from the validation study interviews. The final ontology will be used to produce an assessment of how fully FEARLUS 1-2 is able to represent the aspects of land use and land management change in the study area considered important by farmers and members of related professions in the case study region.
3. Select two past dates (e.g. 1980 and 1992, but final selection not yet made). Using data from the UK Agricultural Census (land use and range of potential land uses), UK meteorological office (climate) and DEFRA (prices), calibrate a FEARLUS 1-2 model of land use change in Upper Deeside on the period between these dates, validate on the period between the second date and the present.
4. Continue work on and with the models of farmer response to possible climate change mitigation policies (in the context of likely future scenarios to 2050), within FEARLUS 1-1, and FEARLUS 1-2.
5. Contribute to work on generalisation of measures and model coherence. This is to be discussed at the project meeting, but FEARLUS's ability to produce output of the kinds exemplified in section 5 should be very useful in this context.
6. Write up the results of the preceding steps for publication.
7. Contribute to the final report.

2.3.9 References

Burton, R. J. F. (2004) Seeing through the 'good farmer's' eyes: towards developing an understanding of the social symbolic value of 'productivist' behaviour. Sociologia Ruralis 44(2):195-215

Gotts, N.M. (2007) Resilience, panarchy and world-systems analysis. Ecology and Society 12(1): 24. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art24/

Gotts, N.M. and Polhill, J.G. (2007) Using Collective Rewards and Social Interactions to Control

Agricultural Pollution: Explorations with FEARLUS-W. Proceedings of ESSA'07 the 4th Conference of the European Social Simulation Association September 10th – 14th 2007, toulouse, France.

Ostrom, E., Gardner, R., and Walker, J. M. (1994) Rules, games, and common-pool resources. Ann Arbor: University of Michigan Press

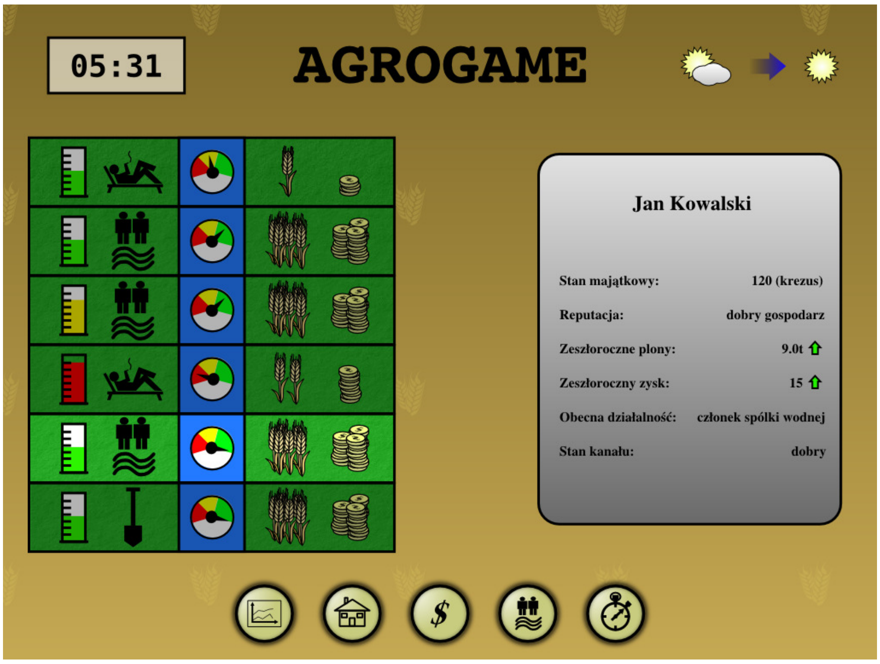
Polhill, J. G. & Gotts, N. M. (2007) Evaluating a prototype self-description feature in an agent-based model of land use change. Proceedings of ESSA'07 the 4th Conference of the European Social Simulation Association September 10th – 14th 2007, Toulouse, France.

2.4 Politechnika Wroclawska

The Wroclaw University of Technology working group consists of the following members: Piotr Magnuszewski, Andrzej Radosz, Grzegorz Holdys, Piotr Goliczewski, Paulina Hetman, Joanna Stefanska, Katarzyna Ostasiewicz, Michal Tyc, Liliana Bujkiewicz, and Andrzej Janutka.

2.4.1 Role-Playing Game for the Odra Case Study

During the last few months we were creating a Role Playing Game for farmers from Odra Case Study, called "AgroGame". The idea is to use this game to validate the model that is being developed by the Kassel team. The game is built on top of the SHAM biophysical model that we have developed for the Kassel model, and a simple economic model. To make the game more attractive, we have designed and created a set of graphics that represent various game concepts like economic condition, profit, or yield. The game is designed for a network play. Each player will have a computer and will connect to the game server via a local connection. The figure below depicts the game's main screen.



Jan Kowalski

Stan majątkowy: 120 (krezus)
Reputacja: dobry gospodarz
Zeszłoroczne plony: 9.0t ⇧
Zeszłoroczny zysk: 15 ⇧
Obecna działalność: członek spólki wodnej
Stan kanału: dobry

Figure #: Main screen of the "AgroGame"

Each player of the game plays a role of a farmer, who owns a parcel. There are six such parcels in the game, each owned by a different farmer. The parcels lay on a piece of land of small and homogeneous slope, along a homogeneous channel, that runs through the centre of every parcel.

The parcels' area and land use is homogeneous. The game works with a yearly time step and in each time step it calculates yields and a simple economic balance for every parcel. At the start of the game, each farmer has the same amount of money. During the game farmers spend their money on agricultural production and optionally on maintaining the ditch. They earn by selling agricultural products. A player can perform certain operations, like cleaning their part of the ditch, joining the Water Partnership, or filing a complaint against a neighbour, who does not clean their part of the ditch. A player against whom such a complaint is filed will have to pay a penalty in the next time step.

2.4.2 Binary Choice (Opinion Dynamics) Models

We investigated some further aspects of binary choice models on finite-size systems of interacting sites. The interaction structure is conceptualized as a graph (network) with edges connecting the agents that interact. We generalized already obtained results. Beforehand, we formulated and proved the sufficient conditions for the transition probabilities of Homogeneous Markov Chain to yield Gibbs distribution relative to given network. In particular we focused on the isotropic case (the neighbourhood influence of an agent via the sum of the attitude over all its members). Now, we formulated the analogous conditions allowing the dependence on a formerly made choice. In other words, we included ‘self-supportiveness’ – a tendency of an individual to sustain her/his opinion. This produces certain inertia in the agent’s behaviour resulting from the psychological tendency toward consistent or habitual behaviour (it can also be interpreted as an agent’s susceptibility to outside influence).

This dependence may be associated with the self-support parameter present in Nowak-Latane and Holyst-Kacperski models.

We also investigated an alternative type of dynamics, i.e the parallel/synchronous updating. Before, we were considering the Monte Carlo dynamics – only one agent updates his/her attitude in a single time step. In parallel case the attitudes of all agents change independently in each time step. The parallelization of single updating changes the stationary distribution. We used the notion of synchronous random processes developed in the field of image restoration and idea of bichromatic graphs.

2.4.3 Evolution of Social Networks - Theoretical model of evolution of an affiliation social network.

The work on a simulation of an affiliation network has been continued. The initial version of the model has been significantly improved. The algorithm was redefined to avoid unnecessary complications while maintaining the critical features of the generated model. The main improvements included:

- simplification and clarification of the algorithm
- allowing multiple group affiliations
- choice of initial degree distribution in the population
- allowing changes in the probability of forming in-group links
- allowing out-group links
- allowing changes in the initial number and size of groups
- allowing changes in nodes' degrees to occur during a simulation (social adaptation)

The role of groups was examined in the context of social network formation. Analytical approach was applied to examine notions of clustering and assortativity that were hypothesized to take specific values for social networks only (as opposed to non-social networks).

Results of the analysis and simulations revealed that existence of groups (with high probability on in-group link formation) does not guarantee high degree correlation. Correlation between node degree and the number of nodes in all groups to which the node belongs contributes to positive degree correlation as well as the correlation between node degree and number of affiliations contributes to positive degree correlation.

Generally speaking, the model allowed to examine various mechanisms that were hypothesized to stand behind high degree correlation coefficient observed in many social networks. Results of the study suggest that high degree correlation is an effect of a certain specific combination of initial conditions and cannot be reasonably expected to occur in all social networks and this conclusion seems to be supported by recent developments of the field.

Our model can also be used as a useful and simple tool to generate networks with desired degree distribution, division into groups and a few other important parameters.

2.4.4 Conference Presentations and Posters

A. Radosz, K. Ostasiewicz, P. Hetman, P. Magnuszewski, M. H. Tyc; "Social temperature - relation between binary choice model and Ising model", International Conference on Complexity, Metastability and Nonextensivity, Catania 1-5 July 2007

K. Ostasiewicz, A. Radosz, M. H. Tyc, P. Magnuszewski, P. Goliczewski; "Equivalence of different binary choice models", International Conference on Complexity, Metastability and Nonextensivity, Catania 1-5 July 2007

P. Hetman, P. Magnuszewski; "How far is the world from what each of us wants it to be? On the relationship between the individuals' decision rules and the resulting equilibrium distribution" International School on Complexity: Course on Statistical Physics of Social Dynamics: Opinions, Semiotic Dynamics, and Language, 14-19 July 2007 Erice, Italy.

P. Hetman, P. Magnuszewski; "Equilibrium properties of evolving binary choice models on networks", XXIII Max Born Symposium "Critical Phenomena in Complex Systems" 2-6 September 2007, Polanica Zdroj, Poland.

A. Janutka, P. Magnuszewski; "Dynamics of probabilistic social-impact model", XXIII Max Born Symposium "Critical Phenomena in Complex Systems" 2-6 September 2007, Polanica Zdroj, Poland.

2.4.5 Plans how to proceed

A working prototype of the "AgroGame" is currently in the final phases of development and we hope to start testing soon. Due to the scarcity of farmers on whom we could test the game, we decided to use sociology students instead. According to current plans, testing on students should begin in October and the actual application of the game for research purposes should occur in winter.

Much effort in the coming months will be devoted to work on conceptual and formal models to measure resilience of complex systems. Previous results on binary choice modes and social networks will be integrated with resilience theory.

3 Case studies

In this chapter the different case study teams report on the work undertaken during the fifth six months of the CAVES project.

3.1 South African case study (SEI Oxford)

Over the past 6 months the SEI team has focused on 2 activities: 1) Pre-validation field trip and 2) Validation working papers. The fieldwork was carried out in Tubatse municipality, Sekhukhune District, Limpopo Province with the Manchester modelling team, in May 2007. Two validation papers were submitted to the CAVES management team.

3.1.1 Sekhukhune fieldwork in April 2007

A CAVES field trip was carried out between 22 and 27 April 2007 in Greater Tubatse Municipality, Sekhukhune District, Limpopo Province, South Africa by SEI and Manchester Metropolitan University. The local participants in the field activities are representatives from Greater Tubatse Municipality and Ga-Selala village. The goals of the trip were:

- To present previous research results to the village and municipal stakeholders for verification and clarification;
- To test assumptions used in the models;
- To ascertain research supported for future development.

Researchers spent three days in the village. First a feedback meeting was held that was open to the whole village. Then focus groups were held with separate men's and women's groups. Some individual interviews were conducted and there were a number of visits to communal projects and village activities. A meeting was held at the Tubatse municipality to feed back results to municipal officials and to provide an opportunity for village and government representatives to discuss the study's key findings and related concerns.

The feedback meeting to the village was attended by about 100 people. Results from our previous fieldwork in 2006 were presented using flip chart sheets. The main issues under 6 headings/themes were presented, namely: water, climate, food, health, jobs and communication; comparing what people in the village had told us about the issue to how the municipality was thinking and talking about the issue (capturing the scale effect and also different priorities). One topic was presented at a time and then opened up for discussion and comment. The response was mainly positive in that people felt we had appropriately captured the key points expressed by people in the village. People went on to place emphasis or expand on certain points and on numerous occasions disagreed with what we were reporting the municipality had said. The process provided a good way of verifying our findings and it highlighted the difference in views and priorities between the village and municipality and the tension that exists between them. People also commented on how pleased they were that we had come back to talk to them about what we had done and found and mentioned their frustration with government for not doing the same.

A visit to the community garden, illustrated that they are still struggling to get it off the ground as water is not available and accessible. A focus group meeting with both the home-based care group and the child care group was informative yet distressing, as they reported that there are 64 child-headed households in the Ga-Selala village and that many health concerns remain unspoken about and care is limited.

Some of the interviews and discussions held in the village were recorded and produced in to a community video to allow of residents of the village to present their own views as far as possible. The video presents the opinions of community members in response to the findings from the first fieldtrip and current issues that are of concern to them. The video can be found on the CAVES website at http://cfpm.org/caves/CAVESWiki/PrivateAreaDocuments .

At the municipality level, the meeting with Greater Tubatse Municipality was welcomed (although attendance was limited) and our report was much appreciated. People hoped it could be used to focus attention from different departments and from the provincial level on the key issues highlighted in the report. The part of the municipal meeting where four representatives from the village joined the discussions was interesting. Again, the findings were presented using the same themes and points and then time was allowed for the village representatives and the municipality officials to offer their views on these issues. Certain issues were raised that allowed the village representatives to express their frustration with the municipality particularly linked to basic services and jobs. The municipality tried to explain their difficulties addressing certain challenges. It was a useful exercise in generating multi-stakeholder dialogue and one that can hopefully be built on.

3.1.2 Validation working papers

SEI Oxford produced two validation working papers for the CAVES project:

- Validation protocol working paper – Deliverable 8
- Case study validation working paper draft – Will be deliverable 10

The validation protocol working paper is mainly based on our discussion at the past CAVES meetings. The aim of the paper is to discuss validation and its role in the project. Validation is used to show the validity of agent based models and their findings without forfeiting their ability to capture complex social realities. The paper includes the following:

- Section 2 reflects on the problems of validating ABMs.
- Section 3 describes approaches that can be used to address the problems of ABM model validation: appropriate design, component validation, and the validation for purpose. This section proposes a sensitivity matrix to prioritise validation activities through a life-cycle of modelling. These actions can be taken to aid validation in the CAVES project.

The significant change from the last draft is a sensitivity matrix to prioritise and select validation activities to fit the purpose of a project and match the situation of the project. The sensitivity matrix approach was adopted because of the conclusion drawn from the validation session at the CAVES meeting, in Vienna in March 2007.

The complimentary paper about the case validation introduces validation actions planned in the CAVES project such as methodology, approaches and protocols. If this draft is accepted at the Kassel meeting, this will be used as a template to document the validation activities of the three CAVES case studies. SEI Oxford will still coordinate and manage the document overall. However, the draft has to be updated by each case team. According to these validation working papers, the next validation trip in South Africa will be carried out in October 2007.

3.2 Grampian case study (Macaulay Institute)

3.2.1 Overview

During the March – September reporting period, the primary field research and validation research phases were completed, as well as their respective reports. An overview of findings is presented in this report. A journal paper based on the field research has been written, and submitted for internal review at the Macaulay; a paper submitted previously has been accepted for peer-reviewed journal publication. The remaining six months of the project will be spent on the final stage of field research, writing journal submissions, and completion of final reports.

3.2.2 Primary Field Research

The primary field research was completed in March, bringing the total interviews to 44 (24 farmers, six successors, five estate factors and nine key informants). The total number of interviewees was 51, reflecting seven farmer interviews in which a partner (typically a spouse) also participated. In most cases these interviews have been transcribed in full[10], and entered into an NVIVO qualitative data analysis software program for examination. First and second stage coding of findings are complete. Findings are being compared with agricultural census statistics on the region, as well as other studies undertaken in neighbouring areas.

3.2.3 Major findings

Land Use Change

Respondents were unanimous that farm size in the region is increasing, supporting this contention with evidence that their own farms had increased in size – often double the previous land base of 20 years before. Production of the primary commodities of the region – beef and sheep – have remained fairly constant in terms of total outputs, but as of 2004 were being produced by approximately 2/3 the number of farms, in comparison to 1987. While consistent with reports of increasing farm scale, this does not necessarily indicate increased intensity of production. Although this was certainly the case on some farms, other farms simply grew larger in land-base, apparently producing at similar or lower intensity, as overall production has not increased, nor has significant agricultural land gone out of production. Production of other commodities: field crops (barley, wheat, turnips, potatoes), dairy, pigs and poultry, have all declined, supporting respondent statements that their farms were producing fewer commodities in general, and fewer arable crops in particular. Engagement in environmental programs is a new phenomenon in the study site, and most of the farmers had some degree of involvement. The extent of land involved in these programs is not yet recorded in census statistics. Labour on the farms has also reduced, with a 29% reduction in full-time occupiers and 26% reduction in staff. The number of part-time farmers has increased, however, as has the number of part-time spouses, suggesting that some farms have made the transition from primary to secondary employment for household members.

Analysis of census statistics demonstrated that the most notable change in land use in the region over the past 20 years was an increase in the area of woodlands: from 700 to 6000 ha. This is most likely due to a government program (the Native Pinewood Scheme) in the late 1980s. The increase in woodlands was mentioned by only one of the interviewees, himself a factor heavily involved in woodland development on his estate. The increase in woodlands will be further explored in the final fieldwork phase.

Decision-Making

Analysis of farmer decision-making focused in two areas: acquisition of new land (through purchase or tenancy) and change in commodity. In the case of land acquisition, the process primarily involves *opportunity*, rather than a formally reasoned business plan. Land is a limited resource, only available when another landholder decides to reduce his or her holdings. This occurs primarily upon the retirement or death of the existing holder, or if the holder goes out of business, and thus access to a specific plot may occur once in 10 – 90 years, depending on farm succession. However, farm land in a neighbourhood would come available on a much more frequent basis (owing to the number of land holders), as demonstrated by the expansion of most farms in the study over the past 20 years. Due to the physical limitations to transport of labour and equipment, land in close proximity to the existing holding is of high value for expansion, which is in turned believed by most farmers to be necessary for ongoing business success. Farmers therefore are very likely to attempt to purchase or rent neighbouring land (particularly it is located immediately adjacent to existing holdings), regardless of the current financial climate, as they believe the opportunity is not likely to recur in the near future.

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[10] Some of the lengthier interviews were transcribed in note form, rather than in full.

In terms of decision-making regarding commodity change, this typically occurs on a '*needs-must*' basis. Economic pressures, such as the high cost of inputs, labour scarcity and declining commodity prices, have driven most commodity changes. Farmers typically act incrementally at first, gradually increasing or decreasing stocking density or acreage of a field crop. In discontinuing a commodity, typically a breaking point is reached, following the gradual decrease, in which production is stopped completely. Examples of this breaking point range from the drop in beef prices following the BSE outbreak in 1996, to the steady decline of potato prices through out the 1960s and 1970s. In both cases, discontinuing the commodity was considered for several years before it was undertaken. Due to the length of time and investment required to re-start a commodity, farmers in the study site will not typically discontinue a commodity on the basis of a single year's poor returns. Nor will they consider changing commodities when they are satisfied with current returns. Although farms have increased intensity of production, the only new 'commodity' in the area is engagement in environmental programs. Farmer respondents indicated that they entered these programs primarily to benefit from resultant subsidies.

Social Networks

In the study, five primary facets of network relationships were addressed: access to information, social norms, resource-sharing and community engagement. Analysis of access to information revealed network structures that were complex and diverse, reflecting the specific commodities and business structures of the farmers involved. For example, a beef producer would likely attend beef cattle sales and information events, whereas a sheep producer would attend sheep-based events. As most producers in the study site produced both commodities, there was considerable overlap in these information networks at a basic level[11]. However, should a third 'commodity' – such as a diversification activity – be added, engagement in other networks reduced of necessity, given the time constraints of the farmer. Farmers must in any case be selective, as there are more information-based events than a single farmer could attend. Choice of information resources also reflects the personal preferences of the farmer: some farmers prefer to gather information from paid advisors, others from livestock shows, and others from travelling input salespeople. Most farmers utilised a combination of these resources. Access to information is therefore not limited to the immediate neighbourhood of the farmer.

Unlike information access, resource sharing was found to be highly localised in geographic terms, as most labour and equipment sharing occurred between immediate neighbours. These relationships are highly based on, and restricted by, trust. For example, while inexpensive pieces of machinery might be shared with trusted neighbours, larger pieces of equipment were only accessible if owner-operated, and therefore usually on a fee for service basis. Similarly, labour sharing was sporadic, and often limited to emergency situations. The value of this labour should not be underestimated, however, given the number of 'one-man bands' operating farms: having a back-up source of labour makes it possible for these farms to continue in existence.

Reputation was found to be important for labour and equipment sharing: farmers are in a position to physically observe the practices of their neighbours, and those believed to be rough with machinery were not trusted with others' equipment. Similarly, those who did not return the favour of labour assistance were not provided with further labour services. Reputation was also a factor in access to rental land (although land sales went to the highest bidder). Land owners prefer to rent land to a 'safe pair of hands' (in terms of both land maintenance and apparent economic success), and used reputation as part of their land allocation decision.

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[11] There is considerable room for differentiation within a commodity category. For example, beef producers selling direct to slaughter would not have a need to attend the live cattle auctions, which historically were the gathering place for beef producer, and continue to act as a market – and meeting place – for some producers. Producers specialising in a particular breed of cattle would attend breed association meetings, and market to a broader geographic spread of similar breed producers, resulting in differential network membership.

Social norms proved difficult to adequately evaluate, as farmers were reluctant to admit that their decision-making was influenced by others' expectations, while key informants clearly believed this to be the case. From the study of farmers' networks, it is clear that a farmer's reference group is not always his immediate neighbours. Instead, farmers may draw social approval from members of a dispersed network, as in the case of breeding society or diversification network members, and therefore be less influenced by more locally held norms. Farmers also refer to positive examples for reference – the 'best' farms in the neighbourhood – rather than all farms equally.

Community engagement was also investigated, but not found to be particularly relevant to land-use decision-making. In general, with fewer people on farms, the 'farming community' is smaller. Farmers also appear less engaged in the local village activities, due to higher labour demands on-farm, and the risk involved in leaving the farm for several hours when there are no other staff to address emergencies which might arise.

3.2.4 Validation

This reporting period saw the completion of the validation research. Validation interviewing was the third phase in the field research process, following the pilot study and primary research stages, and preceding a final phase of field research, in which issues raised in the validation process will be further explored. In the validation process, eight questionnaires were completed with farmers and key informants[12]. The farmers were selected to represent a range of tenures (tenanted and owner operated), ages (41-70), and approaches to farming (traditional vs expanding). The key informants were also chosen to reflect different perspectives. These individuals were a farm business advisor, an environmental program advisor, and a representative of the National Farmers' Union. No factors (estate managers) or farming successors were drawn on for the validation, as the variety of their responses in the primary field research suggested that a single representative of either group would be unlikely to accurately represent, and thus validate, the perspective of these two subgroups.

For the purposes of the validation component of the CAVES project, a questionnaire was derived from model components and assumptions. These include the comprehensiveness and relative importance of factors in land use change, principles of land use change, and the decision-making process. As agent-based models are not intended to be predictive, outputs of the model were not given to respondents for validation. The focus was instead on model inputs and processes. Consistent with the TAPAS (Take a Previous model and Add Something) approach, emphasis in validation is on demonstrating improvements to the model resulting from CAVES field research. Similarly, the particular focus on qualitative aspects of model processes (such as decision-making and social approval) reflects the primary input of the field research into the model. However, the opportunity of the validation exercise was utilised to validate the range of factors included in the calculation farm profitability, and the classification used for agricultural land.

The validation process has generated broad support for the accuracy of the field research, while raising issues for further exploration. Respondents did not identify any major problems with the model inputs and process, and confirmed several aspects which were intended for addition to the model. The following is a summary of validation findings

Validated model components

- Farmers do not change their current crop or type of stock when their aspiration threshold has been reached, even if there are higher prices in a different commodity.
- Innovation is introduced by a small number of innovative farmers, and if successful, copied by other farmers in subsequent years

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[12] This represents 18% of original respondents.

- The profitability of the new commodity is of primary importance, in ordering the factors which farmers take into consideration when changing commodity
- Land is differentially desirable, on the basis of previous (and therefore anticipated) profitability.
- In historical runs, farmers will always bid on neighbouring land, if they have sufficient resources. This is less likely to be true in future-based runs.
- Farmers can be categorised into four sub-types: entrepreneurial, traditional, pluriactive, lifestyle/hobby/environmental. These sub-types act according to different decision priorities.

Important to add to the model

- The principle that farmers will operate at a loss without changing commodity, if no viable alternative exist. Restrictions to this principle on the basis length of time over which loss occurs and extent of loss have not been quantified.
- Off-farm income, as a factor in agents' aspiration thresholds.
- Categorisation of agricultural land: 'arable', 'arable grass', 'woodland', and 'improved grazing' are suitable categories. It may be appropriate to change the term 'unimproved grazing' to 'rough or hill ground'.
- Farmer ability – impacts considerably on farm profitability.
- Including 'well established market for new commodity', 'suitability to current farm set-up' and 'opportunity to benefit from government grants' as factors in decision-making about new commodity up-take
- Including more specifics on proximity of land and expansion plans to decisions regarding land acquisition. (Expansion plans can be handled through farmer type; proximity is currently limited to the current geographic neighbourhood, rather than specifying immediate neighbours)
- Slow speed of farmer response to change events (e.g. one year delay before responding to the Single Farm Payment, a significant system shock)
- Climate change – will differentially impact by commodity and land use type.

Areas for further exploration

- Fixed costs associated with commodities (not in model at present). Important, but there is not a linear relationship between number of commodities and fixed costs.
- Succession (not in the model at present) it cannot be based solely on the initial success of the farm. Perhaps a complex issue best not addressed at this time.
- Organic farming (not an option in the model at present). Social approval may limit adoption, but land suitability and perceived economic benefits appear more important.
- Economies of scale can be utilised as a general principle, but it is also important to consider limitations imposed by other aspects of the farm business.
- No consistent identification of or response to major 'shock' events
- Social approval – difficult to accurately gauge.

3.2.5 Knowledge Transfer Activity

The Knowledge Transfer activity (funded through the Scottish government) described in the March 2007 report was completed in June. Basic study findings were presented to over 20 agricultural industry members at agricultural shows (Thainstone Christmas Classic, the Royal Northern Spring Show, and The Royal Highland Show) in the form of an information sheet (see Appendix), which they were invited to discuss. These individuals confirmed increases in farm size, the relatively slow speed of land use change (including a delayed response to the Single Farm Payment), and that farmer engagement in environmental programs is often economically motivated. However, they also commented that these findings are somewhat specific to the study site region. This is particularly true with regard to perspectives on farm expansion and organic farming. Farmers in other areas of Scotland appear to have more scope for change: crofters were reported to be more responsive to changing markets, and head more quickly into new funding sources (such as environmental programs), whereas larger scale farmers in the north east have more commodities to choose from in terms of land use. North east farmers were also identified as more likely to engage in cooperative ventures. The KT respondents also confirmed the importance of farmer sub-types. Participants indicated that hobby farmers make decisions differently from traditional and entrepreneurial farmers, as their orientation is less economic. They are typically less interested in expansion, but more interested in environmental programs.

3.2.6 Academic Publications

The first paper from the Grampian field research has been written and is currently under internal review at the Macaulay Institute: “Farming in the Network Society: Social Capital Use in Grampian Agriculture” by L. Sutherland (nee Small). A previously submitted paper, “Farm Family Coping With Stress: The Impact of the 1998 Ice Storm”, by L. Small, was accepted for publication by the Journal of Comparative Family Studies. A publication date has not yet been established.

3.2.7 Directions for Future Work

Primary activities for the next six months are as follows:

1. Journal submissions based on the CAVES Grampian field research.
2. Initiation of fourth wave of field research. This is expected to begin in December/January and include 8 - 10 interviews. This research will explore issues raised in the primary field research and validation processes.
3. Completion of final project reports.

3.3 Odra Valley case study (Uniwersytet Wroclawski)

Work was continued in the sub-catchment Prochowice area, where the LRS is not maintained. The second sub-catchment with well maintained LRS, located in the northern part of the Odra River Valley case study region was chosen for further social and biophysical analysis.

3.3.1 Social aspects of land reclamation and land use

The storylines were analysed in terms of aspects, which are important for the further development of the model: agents’ types and economic/social sensitivity of agents. Additionally land use decisions were ordered in the form of a diagram. The economic constraints of farmers' decision making were also under consideration.

The frequency of agents' types

The frequency of agents' types was estimated based on: farms' acreage, economic dependency on farming, personal attitude towards farming activity (willing/unwilling), and the possession of a fishpond. The results are shown in Tab.1, where FPO means Fishpond Owner, WPTF means Willing Part Time Farmer, UPTF means Unwilling Part Time Farmer, and BF means Big Farmer.

	FPO	not FPO	total
WPTF	2	8	10
UPTF	0	3	3
BF	2	2	4
total	4	13	17

Tab.1 Distribution of agents types in Rogow Legnicki

Economic/social sensitivity of agents

The assessment of social and economic sensitivity of agents in Rogow Legnicki was based on their reasoning about decisions they take. There were five areas of decision making under consideration: past, present and future land use, land reclamation maintenance, and participation in a Water Partnership. During interviews farmers were asked about reasons of their decisions in case of every of these issues and the results can be found in the relevant five sections of agents storylines. These sections (the same in every storyline) were analysed in order to quantify the economic/social sensitivity of agents as weighs attached every agent. The points were given for decision drivers in the following way: 1 point for economic sensitivity if any economic reasons/factors were indicated, 1 point for social sensitivity if any social reasons/factors were indicated, 0 points if neither economic nor social reasons/factors were indicated. This last situation is quite common since farmers often talked about different than economic and social drivers of their behaviour that are not included in the model, e.g. personal attitudes and convictions, habits or practical issues of environmental or technical nature. Every agent could get maximum 5 points for economical, and 5 points for social sensitivity. In fact none of them got the highest score. The mean economic sensitivity (2.88) is higher than mean social sensitivity (1.00). In some way it goes along with the results of recent social research which present the level of social trust in Poland as one of the lowest in Europe.

Economic constrains of the agent decisions

Economic calculator for assessing agriculture profitability was developed. The calculator was used to generate the economic situation in the validation game, as well as in the ABM developed by the Kassel team. The historical changes in agriculture profitability were studied as a factor influencing LU decisions and a driver of LULC changes.

Land use decisions

Based on storylines land use decisions paths were generated in the form of diagram. This diagram may provide a start for land use change algorithms/rules development in the spatial land use/land cover change model.

Research report

The research report is under preparation. The report includes the following parts:

4. Research problems

5. Study area
6. Methods
    - Population of concern and sampling
    - Research tool
    - Organization of the research process
    - Data processing and analysis
7. Results
    - Question 1: What are the main land use change processes in the Odra case study region and what are their causes?
    - Question 2: What kind of decisions do farmers take with respect to land use and what are the reasons of these decisions?
    - Question 3: What kind of decisions do farmers take with respect to LRS maintenance and what are the reasons of these decisions?
    - Question 4: What is the nature of social networks in the study area?
    - Question 5: What are the social, institutional and economic drivers of collective action related to LRS maintenance?
8. From research to modelling – data transfer
    - Agents design
    - Rules design
9. References

3.3.2 Analysis of biophysical components of the system

Meteorology

Wrocław-Biskupin meteorological station (51° 07’ N, 1° 05’ E, 116.3m AMSL), located in the Odra Valley 80 km SE from the case study region, was chosen to represent the meteorological conditions of the case study region.

The set of meteorological parameters that are important for the simulation of water balance was specified. Statistical analysis performed on meteorological time series (1946-2003) allowed to identify two extreme years (wet and dry) and one average year which are used as model years for the weather simulation in the simple biophysical model. The time series were also analysed in terms of climate impact on land use and the following paper is being prepared at the moment: Climate as a driving force of LULC changes in Middle European lowland agricultural landscape. It is planned to be submitted to the Agriculture, Ecosystems and Environment.

Hydrology

The method of hydrological model calibration was developed. The meteorological and hydrological measurements are being realised. The collected data will be used to calibrate the hydrological model.

Spatial structure of the LRS channel/ditches vegetation (LRSVeg) and crops submodel

The vegetation within and along channels and ditches plays a very important role in water and nutrient dynamics. The structure of this vegetation is influenced by land reclamation system maintenance. If it is neglected the vegetation follows ecological succession. This process depends on local environmental conditions and is also affected by the neighbouring fields. During the succession grassland vegetation developed on the channel/ditches' banks is replaced by shrubs or rush. These two types of vegetation modify water flow in different ways. Shrubs grow mainly on the banks and shadow the water body of channel. It leads to the reduction of the plant cover within a channel and keeps the channels/ditches' body open for the water flow. On the contrary, rush grow mainly in the water body and decrease the water flow. Since channel vegetation is important both as a water flow control factor and as an indicator of the land reclamation system maintenance, detailed maps of its spatial structure were done in the Prochowice region, where the LRS is neglected and in the Peclaw region, where the LRS is maintained.

Plant data for crop sub-model is being prepared.

Geo database development

Historical land cover was digitised within the catchments where Rogow Legnicki is located, from archival 1:25 000 topographical maps from 1930s. The data will be used for land cover change analysis.

In addition to historical topographical maps, a historical ortho-photo map from 1930 was integrated into the Odra case study GIS database. Although its coverage is incomplete, about 50% of the total case study area, it is a valuable data source supporting the interpretation of archival topographical map features.

Soil quality GIS data for the biophysical model area was alos integrated into the Odra case study GIS database.

Land use/cover change

Recent and previous land use/cover (LULC) was analysed using the GIS GRASS software. The paper containing these results is under preparation.

3.3.3 Model validation

The general concept of the validation game was developed, including the list of assumptions included in the model that need to be validated. This work was done with the assistance of Dr Barbara Pabjan from the Institute of Sociology, Wroclaw University, and in strict cooperation with the project partners from Wroclaw University of Technology.

The general assumptions to be validated include

- economic success and social support as main decision drivers;
- the construction of social support factor in the model (based on opinion dynamics theory);
- the construction of economic success depending on yield perception;
- weights of economic and social sensitivity.

Other discussed issues included:

- the form of the game (individual or group; board or computer);
- the general experimental scheme, especially number and types of variables to be included and controlled, as well as number of players, scenarios, runs, and repetitions;
- the way of presenting economic reality (e.g. real prices and currency or not);
- the way of including social pressure: support and disapproval;
- the (graphical) user interface;

- further knowledge elicitation (e.g. in-depth interviews after the game to going deeper into farmers’ reasoning).

3.3.4 Publications

The following paper was submitted to JASSS: Krebs F., Elbers M., Ernst A., Krolikowska K., Holdys G., An Evidence-Based Model of Farmer Decision Making: Contrasting Social Support and Economic Success.

3.3.5 Next steps

Social aspects

- Further development of detailed rules governing land use/cover change that could be integrated with the spatial land use/land cover change model;
- Additional research in the area, where land reclamation seems to work properly (Peclaw Commune);
- Continuous cooperation with the modelling team on further model development;
- Realization of the validation game.

Biophysical aspects

- Integrate the remaining soil quality maps into GIS database, for the whole case study area.
- New photogrammetry-based DEM (Digital Elevation Model) is being worked on. It's going to replace DEM interpolated from digitised elevation contour lines in order to improve the biophysical model. The new DEM is going to cover the rest of the Odra case study area too.
- Meteorological and hydrological data collection will be continued for the calibration and validation of biophysical model.
- Meteorological time series data and economic time series data will be analysed as the driving force of land use/cover changes to define evidence for LULC changes model.
- Evidence collection for crops sub-model will be finished.
- Other types of activity will be added to the economic calculator.
- Spatial analysis of landscape changes and its influence on the main landscape function will be performed.
- Methodology for the social model output translation to the biophysical model will be developed.

Publications

The following papers will be prepared:

- Agricultural landscape changes driven by socio-ecological changes in the rural areas before and after the accession to EU (will be submitted to the Agriculture, Ecosystems and Environment)
- Driving forces of LULC change in the agricultural landscape of new EU membership countries: case study Odra valley (Poland) (will be submitted to the Landscape and Urban Planning)

- The problems of land reclamation system maintenance in Central Europe: Odra River Valley case study (Poland) (will be submitted to the Journal of Rural Studies)
- Integrated approach to collective action in land reclamation systems management: social research, GIS and agent based modelling (will be submitted to the Agricultural Systems)

4 Publications

The CAVES project is dedicated to publishing results in relevant scientific journals and conferences. Nearly all of the submitted papers from the last reporting period have been accepted at their respective conferences and presented successfully.

During the fifth six months of the project, the following papers have been written:

- Shah Jamal Alam, Ruth Meyer and Emma Norling: *Agent-based Model of Impact of Socioeconomic Stressors: A DYNAMIC Network Perspective*. In: Proceedings of the Sixth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS'07), May 14–18, 2007, Honolulu, Hawai'i.
- Shah Jamal Alam and Ruth Meyer: *Analyzing Network Evolution in Agent-based Models using Subgraph Characteristics*. In: Proceedings of the UK Social Network Conference, London, 13-14 July 2007, pp. 86-88
- Shah Jamal Alam and Ruth Meyer: *Structural Changes in Dynamical Networks Generated from Agent-based Simulation Models.* In: Proceedings of the Fourth Conference on Applications of Social Network Analysis (ASNA 2007), 13-15 September 2007, Zurich, Switzerland (forthcoming)
- Shah Jamal Alam, Ruth Meyer and Bruce Edmonds: *Signatures in Networks Generated from Agent-based Social Simulation Models*. CPM Report No.07-176, online available at <http://cfpm.org/cpmrep176.html>
- Friedrich Krebs, Michael Elbers, Andreas Ernst, Karolina Krolikowska and Grzegorz Holdys: *An Evidence-Based Model of Farmer Decision Making: Contrasting Social Support and Economic Success*. Submitted to the Journal of Artificial Societies and Social Simulation (JASSS)
- Friedrich Krebs, Michael Elbers and Andreas Ernst: Modelling Social and Economic Influences on the Decision Making of Farmers in the Odra Region. Proceedings of the 4th Conference of the European Social Simulation Association (ESSA'07), 10 – 14 September 2007, Toulouse, France
- Nicholas M. Gotts: *Resilience, panarchy and world-systems analysis*. Ecology and Society 12(1): 24, 2007. Online available at <http://www.ecologyandsociety.org/vol12/iss1/art24/>
- Nicholas M. Gotts and J. Gary Polhill: *Using Collective Rewards and Social Interactions to Control Agricultural Pollution: Explorations with FEARLUS-W*. Proceedings of the 4th Conference of the European Social Simulation Association (ESSA'07), 10 – 14 September 2007, Toulouse, France.
- Scott Moss: *Alternative Approaches to the Empirical Validation of Agent-Based Models.* Online available as CPM Report No. 07-178 <http://cfpm.org/cpmrep178.html>
- J. Gary Polhill and Nicholas M. Gotts: *Evaluating a prototype self-description feature in an agent-based model of land use change.* Proceedings of the 4th Conference of the European Social Simulation Association (ESSA'07), 10 – 14 September 2007, Toulouse, France.

- Lee-Ann Sutherland (nee Small): *Farming in the Network Society: Social Capital Use in Grampian Agriculture.* Currently under internal review at the Macaulay Institute.
- Bogdan Werth, Armando Geller and Ruth Meyer: *He endorses me – He endorses me not – He endorses me…Contextualized reasoning in complex systems*. Accepted for the AAAI 2007 Fall Symposia, Washington, DC, November 8–11, 2007

5 Deliverables

5.1 Current Deliverables

There are no Deliverables due at the end of project month 30. The delayed Deliverable No. 8, the working paper on case study structure, stakeholder/agents and validation data, is now available from the CAVES internet portal at `http://cfpm.org/caves/CAVESWiki/Publications`.

5.2 Future Deliverables

With the end of the project, several major Deliverables will be due during the next reporting period. These are:

No.	*Title*	*Lead*	*Project Month*
10	Working paper on case study validation	SEI	33
11	Working paper on modelling and case studies in policy analysis process	MMU	35
12	Working papers on results from each case study	SEI	36
13	Final models as open source libraries	UNIK	36
14	Technical reports on the final models	UNIK	36
15	Handbook on conceptual and formal models to measure resilience of complex systems	WUT	36
16	Final Report	MMU	36

In accordance with the extension of the CAVES project, all of these Deliverables will be pushed back by two months, i.e. the length of the extension.