Modelling the Social and Economic Dimensions of Farmer Decision Making under Conditions of Water Stress

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Abstract

In this paper, we report on an agent-based model with a coupled hydro-agricultural model that simulates the collective decision making of typical landowners in the Odra River catchment under fluctuating socio-environmental boundary conditions. We start out from case evidence. Farmers in the Odra region of Poland are caught in a social dilemma: While, in principle, the existing land reclamation system (LRS) of ditches and canals can absorb the negative effects of extreme weather conditions, its proper functioning requires collective action as regards maintenance. However, such a collective effort is undermined by the asymmetrical nature of the dependency of farmers resulting from the different locations of their land parcels along the LRS. In the model farmers decide whether to maintain their local section of the LRS or not based on their economic success and the social support they receive from acquaintances. Simulation results indicate that the frequency of LRS strategy changes - an indicator for overall volatility - is reduced with the introduction of social influence and that further social pressure leads to a positive lock-in that even prevents free-riding behaviour.

Keywords: Collective Action, Informal Institutions, Social Networks, Volatility, Water Use, Opinion Dynamics

Introduction

The purpose of the CAVES (Complexity, Agents, Volatility, Evidence, and Scale) project is to understand complex human-environmental systems by means of simulations based on integrated biophysical, social and policy models. To achieve this aim we study key phenomena of complex human behaviour regarding land and water use in three case studies. The main focus lies on the influence of social networks on environmental behaviour. CAVES includes case studies in Great Britain, Poland, and South Africa to acquire data on real world evidence of social networks.

The Polish case study, with input provided by the University of Wroclaw and the Wroclaw University of Technology, is concerned with issues of land use and water management in the Odra river region. More specifically, it focuses on those parts of the region that are prone to regular flooding due to a lack of maintenance of an old land reclamation system. Maintaining or re-establishing this land reclamation system (LRS) which consists of canals and ditches requires social mobilisation of the farmers concerned. Thus it is important that the acquaintance and/or friendship relationships that exist amongst farmers are utilised appropriately. Moreover, it is suspected that land reclamation, being a collective action (Olson 1965; Ostrom 1990), possesses the structure of a social dilemma (Dawes 1980). If so, existing work can be built upon to investigate this issue further.

The decision making of farmers about participating in the maintenance of the LRS is one of the main sources 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. Thus, 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 in this paper on a rather isolated examination of the socio-environmental dynamics of farmers' LRS decisions.

Agent-based modelling (ABM) approaches are especially suitable for these kinds of domains (see e.g. Bousquet and Le Page 2004; Gotts, Polhill, and Law 2003) because they allow for a bottom-up representation of individual actor's decision making based on local (subjective) perceptions of a common social and physical environment. The goal of the agent-based model presented in this paper is to test how different assumptions about farmers' social and economic orientations drive or inhibit the installation of a working LRS.

The integrated simulation model of the Odra river region that we present consists of two main components: The hydro-agricultural model provides insight into the costs and benefits of farming and land reclamation under certain climatic conditions. Complementing this, the agent-based model called SoNARe (Social Networks of Agents' Reclamation of land) seeks to capture key aspects of the reasoning of the actors involved and their interactions with their biophysical and social environment. It is based on an explicit representation of social influence that is exerted and perceived in social networks on the one hand and the individual agents' perception of economic success that is derived from feedback of the coupled hydro-agricultural model on the other hand. These two central dimensions (social influence, economic success) drive and determine the agents' decision making as regards farming and LRS maintenance as well as social behaviour.

In this paper, we first outline the set of issues that characterise the complex of problems encountered in the case study. This is followed by a detailed description of the model itself, in particular its agent-based core component (SoNARe). Subsequently, results of initial simulation runs for two basic scenarios are presented and discussed followed by a first sensitivity analysis. Besides other behavioural indices used in the results section, a measure of volatility (the amount of strategy changes by the actors) is identified.

Land Reclamation in the Odra River Region

The LRS consists of canals and ditches, that drain the soil directly or through a drainage pipes system, and thus the LRS protects a field against flooding — in the following, the term 'channel' is used for both canal and ditch. The LRS maintenance process mainly involves the periodic cleaning of canals and ditches, e.g. by removing vegetation and sediments from the channels' beds.

In principle, if viewed independently from other channel sections, the maintenance of the local section of the LRS serves to alleviate or even eliminate the negative effects of extreme weather conditions, especially excess water stress in the case of flooding, whereas neglecting 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 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 it facilitates runoff. The latter effect arises even if the upstream neighbours do not themselves maintain their section of the LRS (free riding).

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

The development of a social model starts with the elicitation of the most important types of actors involved and an abstraction of their decision processes. Obviously, in our work the central actor type is the farmer. In the work presented here we had the opportunity to use transcripts of interviews that were conducted with farmers in the target region.

When farmers are asked about their motivations concerning LRS maintenance, they state that they would either maintain the LRS if they had sufficient economic resources or if there was enough social support for LRS maintenance. The economic dimension of LRS maintenance is mainly determined by the achieved stability in attained crop yields over years with climatic extremes (flooding/drought) but it also includes factors like buying the required equipment or paying others to do the work. Social support towards LRS maintenance may e.g. originate from observing other farmers maintain their local LRS facilities properly and gaining protection against environmental fluctuations and shocks. A second source of social influence originates from actors actively trying to initiate a working LRS. Usually, these initiators are people from local authorities. In addition, farmers can 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. For instance, farmers mention professional advisors forming Advisory Centres. As an abstraction we regard all these types of leader personalities as 'LRS initiators' in that they influence farmers in their decision to maintain the LRS and to participate in the collective action. Accordingly, LRS initiators form the second actor type that is represented in the social model.

The economic driver of farmers' decision making relates to losses in crops in case of flooding or drought over a sequence of past years. The social dimension of farmer decision making is captured by modelling aspects of social influence between farmers. We use concepts of general opinion dynamics (cf. Latané 1981; Friedkin 1998). It is assumed 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 LRS initiator actor asking to join in the collective action. Implementation details are given in the modelling section.

Model Description

The overall model presented here consists of two sub-models. The SoNARe model is the main sub-model which this paper focuses on. SoNARe aims to capture farmer decision making and some of the key 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 climatic 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 an LRS initiator. Initiator 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 making: The behaviour of the LRS initiator actors reflects their reasoning about when to trigger collective action. Farmers decide about partaking in LRS maintenance taking into account 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 channels.

Extreme weather conditions: The effects of LRS maintenance and their impact on yields are most crucial under extreme weather conditions.

The first three problem features are covered by the SoNARe model that is described in detail in the next section. This is followed by a section that documents the hydro-agricultural model which deals with the other three problem features.

The SoNARe Model

Social and physical environments

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. In our model the topology of the physical environment is reduced to a chain of land parcels that is located along a channel of the LRS. Each land parcel is managed by one agent. The agent's location is given by the position of its land parcel at the channel. The social "location" of an agent is given by the agent's 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, Flache, Delgado, and Sangüesa 2005). In the same way, the agents' repertoires of actions differ relating to their respective environment.

In the model version presented in this paper, the actions related to the natural or physical environment have been reduced to the farmer agents' binary decision of 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. Technically, an agent has slots that are nodes representing potential or actual social roles in different networks, so the networks actually reside in the agents' memory (cf. Ernst, Krebs, and Zehnpfund 2007, for an example model using two social network layers). We assume a scale-free topology since this is supported by Odra case study narrative storylines as well as many other studies on social networks (cf. Barabási 2002; Newman 2003).

Unlike in other network modelling approaches, agents do actively perceive their social environment and are enabled to act in their social network. We investigate the exertion and perception of social influence as ways of "acting in" and "perceiving" a given social environment. We use a one-layer and static social network that serves as the infrastructure for perceiving and exerting social influence.

The two agent types represented in the current version of the SoNARe model differ distinctly in the ways they are embedded in their social and physical environments. The farmer agents and the LRS initiator agent are embedded in a common acquaintances network. The evidence that an initiator has a high degree of social network integration is covered by the fact that the corresponding 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 these links can span a number of hydrologically independent channels). The Odra case study suggests that most LRS initiators are not farmers themselves, but village mayors or external advisors. Therefore, in the model LRS initiator agents do not interact with the simulated physical environment whereas 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

The economic success (*economicSuccess*) farmers perceive 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 varies across agents. 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. To calculate the agent's current perception of economic success we sum up all the stored values in yield memory and normalise to the codomain [0,1] such that values below 0.5 represent "negative economic success" while values equal to or above 0.5 reflect "positive economic success".

The scale-free network which forms the infrastructure by which agents exerted and perceive social support is generated by an algorithm described by Ebel, Davidsen, and Bornholdt (2002). This algorithm allows generating a sufficient proxy of a scale-free network (in the simulations presented here it contains 100 nodes and an average node degree of 10). As pointed out before the LRS initiator is added to this network and linked directly to all farmers.

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 LRS initiator. 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. Again, the final indicator of an agent's perceived social support is calculated as a normalised sum of all social influences such that values below 0.5 represent "negative social support" while values equal to or above 0.5 reflect "positive social support".

Decision making

The LRS initiator agent being embedded in the social acquaintance network partakes in the general opinion dynamics as regards LRS maintenance only in that it exerts social support, the magnitude of which being defined in relation to that of farmer agents. It is assumed that the LRS initiator possesses information about the economic success of its acquaintances, i.e. the direct network neighbours in the social network. An LRS initiator agent decides to exert its social influence in favour of LRS maintenance whenever it perceives a minimum number of farmers who have big losses; i.e. farmers whose individual economic success is below 0.5. The LRS initiator does not exert any influence otherwise.

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. The *decisionBias* of a farmer is represented as a value in the range of [0,1] where values above 0.5 stress the economic influence on decision making, values below 0.5 stress the social dimension. Since the two perceptions are normalised, the combined decision criterion of a farmer agent is calculated as a weighted sum in which *economicSuccess* is weighted with *decisionBias* and *socialSupport* is weighted with (1-*decisionBias*).

The final decision making is based on the weighted sum and abstracted in the form of a Win-Stay, Lose-Shift strategy (Nowak and Sigmund 1993), i.e. a farmer agent keeps to its previous behaviour (maintaining or not maintaining the LRS) if the calculated decision criterion is sufficiently high (>0.5) otherwise the farmer agent shifts to the opposite behaviour.

The Simple Hydro-Agricultural Model

The Simple Hydro-Agricultural Model (SHAM) is a quasi two-dimensional abstraction of the environmental situation typical for the Odra region. It reflects the hydrological dependencies between neighbouring land parcels and simulates the effects of different weather conditions, LRS maintenance and LRS neglect and the crop yields of individual land parcels along a channel. The model assumes a specified number of parcels located on a terrain of small and homogeneous slope, along a homogeneous channel, that runs through the centre of every parcel. Each parcel has the same area. At the end of every simulation year, the model calculates stylised yields from every parcel. A farmer agent that operates on a given parcel can perform LRS maintenance i.e. cleaning the segment of the channel located on its parcel, or neglect the LRS. Yields depend on the average water level in a given parcel; extreme water levels reduce the attained yield. Because the model handles some spatial effects, like water lifting due to a clogged segment of the channel, the yields are affected not only by phenomena taking place on a single parcel, but also by those which happen in the surroundings.

The general dynamics of the model are as follows. For normal weather conditions SHAM shows a negligible impact of the LRS condition on the crop yield. In wet years LRS maintenance generally increases the crop yield with a higher effect upstream. Also, when large sections of the channel are well maintained downstream farmers experience a loss in yield because all excess water from the upstream parcels is drained through their parcels. Moreover, downstream farmers obtain a degree of implicit flood protection form upstream farmers not maintaining their LRS.

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. All farmer agents appraise their crop yield as "good" or "bad" with respect to a yield threshold of 9. The agents' yield memory capacity, however, is heterogeneous; it is randomly assigned 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.

We simulate 100 farmers located along 10 hydrologically independent channels, i.e. it is assumed that hydrological interrelations only exist within one channel but not among individual channels.

Farmer agents and LRS initiator 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 initiator agent that becomes active if at least 3 farmers have big losses, i.e. *economicSuccess* being negative, and accordingly it becomes passive again if less than 3 farmers have big losses. The LRS initiator agent possesses social network ties to all farmer agents and when active, it exerts social influence in favour of LRS maintenance with its influence level set to 3.

All 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. 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.

Scenario 1 – The influence of economic success

In this scenario farmer agents base their decisions exclusively 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 LRS initiator 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) and feed back to the decision dynamics.

Figure 1 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 7 years of simulation time and then gradually falls back almost to zero. Figure 2 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.

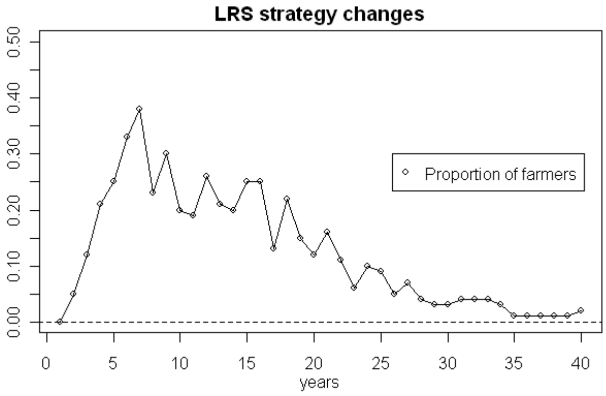

Fig. 1. Strategy changes over time as an indicator for volatility. Each dot marks the proportion of farmers who have switched their LRS strategy in one year (40 years in total). Note that the change can be either way, i.e. in favour of or against LRS maintenance.

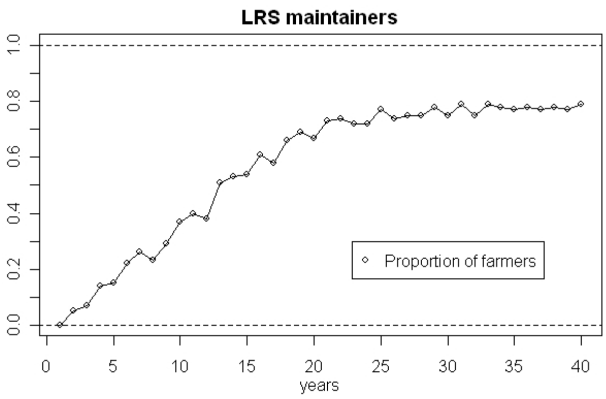

Fig. 2. Proportion of LRS maintaining farmers over time.

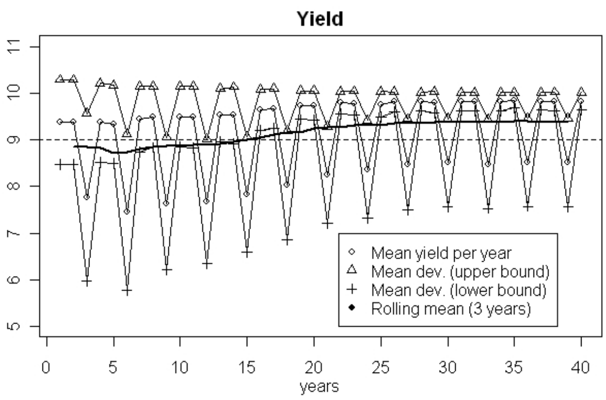

Fig. 3. Average yields of farmers bounded by the mean deviation and the rolling mean over three consecutive years. The dotted line indicates the yield threshold.

Figure 3 shows an increase in the average of farmers' crop yields. Notice that the wet years are reflected in the regular pattern of low 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 4, the perceived economic success of LRS maintainers increases substantially and then settles on a slightly higher level than the corresponding values for non-maintainers.

Scenario 1 illustrates the temporal 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. 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.

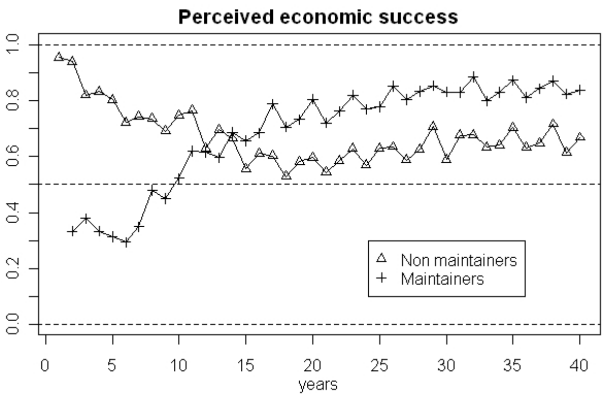

Fig. 4. Mean perceived economic success of maintainers and non-maintainers over time with the yield threshold set to 9.0, a decision bias of 1.0 and a mean yield memory capacity of 5 years with radius 2. The perceived economic success is normalised to the interval [0, 1].

Scenario 2 – The combined influence of economic success and social support

In the second 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 LRS initiator agent has a social influence level of 3 (i.e. it is three times as influential as a farmer agent). The scale-free acquaintances network used in the simulation comprises 100 nodes with an average node degree of 10.

As the simulation starts out with no LRS maintainers, the general opinion dynamics between farmers initially generate perceptions of high social support for LRS neglect. Since in addition the initiator 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 5 shows the proportion of farmers who change their opinion about LRS maintenance as an indicator of the system's volatility. Figure 6 shows the corresponding convergence of the number of LRS maintainers to a stable state of 100% after 26 years. Around year 15 the barrier of 50% LRS maintainers is breached which triggers an avalanche pro LRS.

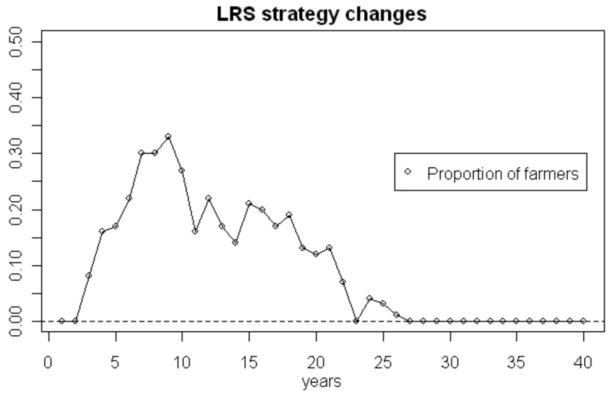

Fig. 5. Strategy changes over time as an indicator for volatility. Each dot marks the proportion of farmers who have switched their LRS strategy in one year. Note that the change can be either way, i.e. in favour of or against LRS maintenance.

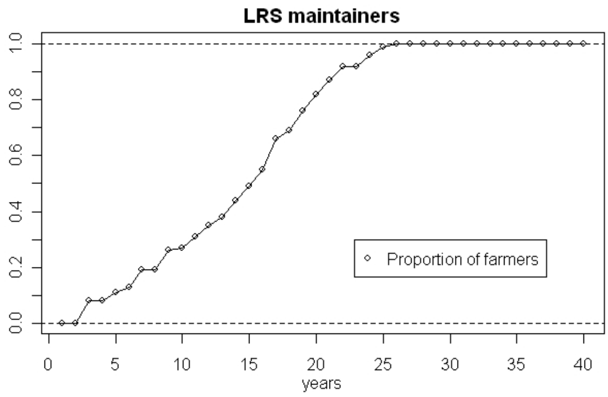

Fig. 6. Proportion of LRS maintaining farmers over time.

Figure 8 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 the agents' 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 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 LRS initiator becomes passive (see Figure 8). 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 maintenance) 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 LRS initiator. Accordingly, the perceived social support drops below 1.0 when the initiator becomes passive.

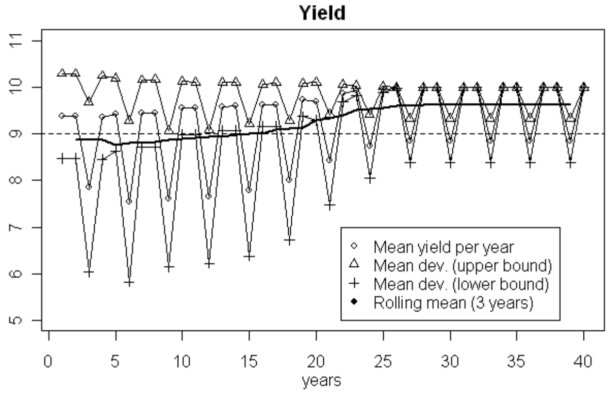

Fig. 7. Average yields of farmers over three years bounded by the mean deviation and the rolling mean.

Figure 7 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.

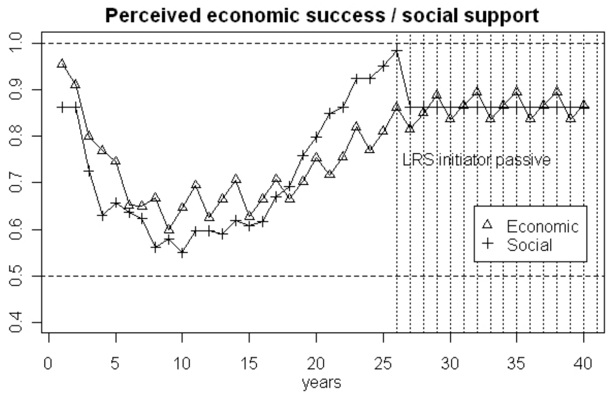

Fig. 8. Mean perceived economic success and mean perceived social support over time.

In scenario 2 it is assumed that in addition to appraising their economic success farmers also include the perceived social influence in their decision process. Once the LRS initiator gets active it continuously pushes the opinion making process towards LRS maintenance. Figure 8 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, such as those observed in scenario 1, to partake in the collective action.

Sensitivity Analysis

This section reports on a first sensitivity analysis of the model. For this purpose we varied the parameter *decisionBias* from 0 to 1 with a step size of 0.025 and varied the relative social influence of the LRS initiator from 0 to 7 with a step size of 0.25. Note that in scenario 1 *decisionBias* was set to 1.0 and in scenario 2 this parameter was set to 0.5 and relative social influence of the LRS initiator was set to 3.0. All other parameters remain fixed as in scenarios 1 and 2. In the following figures the minimum values are coloured in black, maximum values are coloured in white and the values in between are represented by shades of grey from black to white.

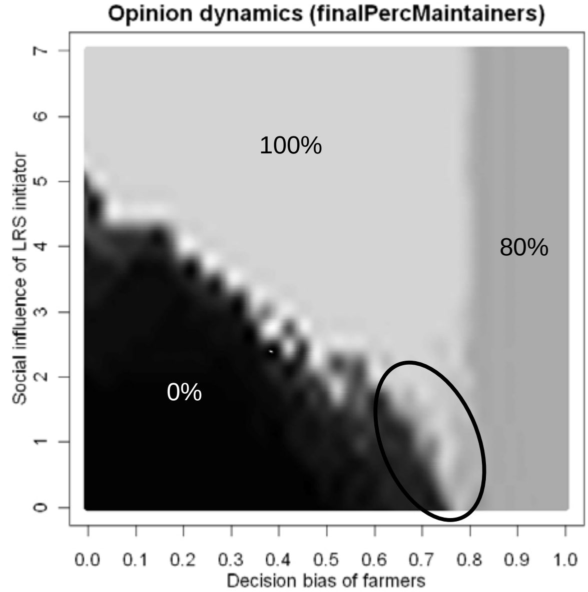

Fig. 9. Final fraction of LRS maintainers after 40 years.

Figure 9 shows the proportion of maintainers after 40 years of simulation. The right hand side of the diagram with *decisionBias* above 0.85 confirms the observation made in scenario 1 that with a high economic orientation roughly 80% of the farmers contribute to the collective action. With a lower decision bias 100% of the farmer agents get mobilised if the social influence level of the LRS initiator is high enough. The lower left region of the diagram shows that with a higher social orientation (i.e. a lower *decisionBias*) farmer agents keep to their initially passive behaviour and never maintain the LRS unless high influence levels of the LRS initiator are assumed. A highly influential initiator is required to break up the social coherence of the initially passive population of farmers.

Figure 10 displays the mean volatility of the opinion dynamics over 40 simulation years. Most interesting is the marked region of relatively high volatility which is between 20% and 23%. When compared to the same region in figure 9 it seems that this phase of high volatility is associated with a transition between 100% mobilisation and close to 0% in the relevant parameter range.

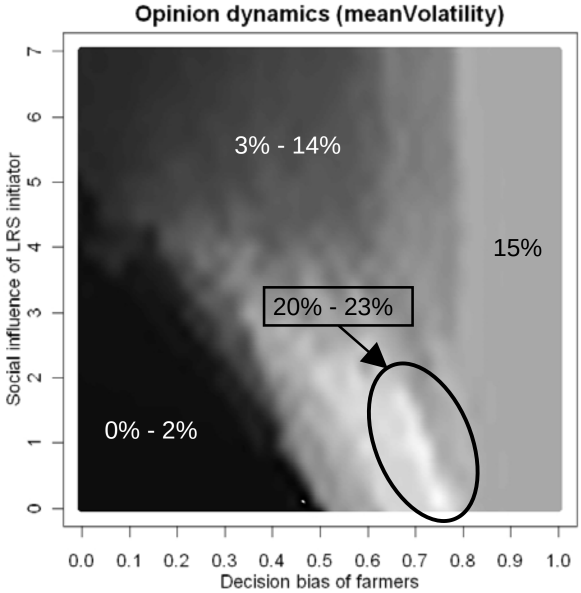

Fig. 10. Mean volatility in the opinion dynamics after 40 years.

Discussion

The presented integrated model comprises an abstract biophysical model that reflects the main hydro-agricultural properties typically found in the Odra river 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 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 points in the direction of a social dilemma induced by the hydrological interdependencies of farmers' land parcels. Scenario 2 adds social influence to the decision process which results in the emergence of a positive social lock-in.

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 1 and 2 (see Figures 1 and 5) one can observe that for scenario 1 the indicator has peaks to almost 0.4, whereas in scenario 2 the indicator is always well below 0.35. Moreover, in scenario 2 the indicator drops to zero earlier than in scenario 1. 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 dependency structure prone to free riding, a social "activity seed" together with some social and economic pressure on the participants is sufficient to trigger a social lock-in in favour of LRS maintenance. 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 LRS initiator.

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