International Environmental Modelling and Software Society (iEMSs)
2012 International Congress on Environmental Modelling and Software
Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany
R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp (Eds.)
http://www.iemss.org/society/index.php/iemss-2012-proceedings

The role of social interaction in farmers' climate adaptation choice

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Abstract: Adaptation to climate change might not always occur, with potentially catastrophic results. Success depends on coordinated actions at both governmental and individual levels (public and private adaptation). Even for a "wet" country like the Netherlands, climate change projections show that the frequency and severity of droughts are likely to increase. Freshwater is an important factor for agricultural production. A deficit causes damage to crop production and consequently to a loss of income. Adaptation is the key to decrease farmers' vulnerability at the micro level and the sector's vulnerability at the macro level. Individual adaptation decision-making is determined by the behavior of economic agents and social interaction among them. This can be best studied with agent-based modelling. Given the uncertainty about future weather conditions and the costs and effectiveness of adaptation strategies, a farmer in the model uses a cognitive process (or heuristic) to make adaptation decisions. In this process, he can rely on his experiences and on information from interactions within his social network. Interaction leads to the spread of information and knowledge that causes learning. Learning changes the conditions for individual adaptation decision-making. All these interactions cause emergent phenomena: the diffusion of adaptation strategies and a change of drought vulnerability of the agricultural sector. In this paper, we present a conceptual model and the first implementation of an agent-based model. The aim is to study the role of interaction in a farmer's social network on adaptation decisions and on the diffusion of adaptation strategies and vulnerability of the agricultural sector. Micro-level survey data will be used to parameterize agents' behavioral and interaction rules at a later stage. This knowledge is necessary for the successful design of public adaptation strategies, since governmental adaptation actions need to be fine-tuned to private adaptation behavior.

Keywords: *drought; agriculture; private adaptation; sector vulnerability, agent-based model*

1. INTRODUCTION

Even though the Netherlands is a 'wet' country with a maritime climate, it is likely that droughts will occur more frequently and will become more severe due to climate change (Ministerie van Infrastructuur en Milieu, 2009). Water is a vital production factor for the agricultural sector; droughts reduce the water availability for crop growth causing crop damage, a loss of yield and eventually a loss of farm income. Besides water quantity problems, droughts provoke water quality problems due to salt intrusion in surface and groundwater resources. Too high salt concentrations can bring about crop damage depending on the salt tolerance of a crop (van Bakel and Stuyt, 2011).

The initiation of the Deltaprogram, a national program with among other things the aim to secure the freshwater supply in the long run, shows that the Dutch government acknowledges the significance of future climate-induced drought problems (Ministerie van Verkeer en Waterstaat, 2010). First estimates within the scope of this program indicate that the economic loss to the Dutch agricultural sector may reach 700 million € in a 'dry year' with a precipitation deficiency of more than 220 mm in summer (frequency of 1/10 years). In an 'extreme dry year' with a precipitation deficiency of over 360 mm in summer (frequency of 1/100 years) the economic loss to the agricultural sector may reach 1800 million €. This is equal to 0.1% and 0.3% of GDP respectively. Due to climate change and socioeconomic developments these damages might increase fivefold in 2050, meaning that the agricultural sector will face a loss of 700 million € once every two years (Ministerie van Economische Zaken Landbouw en Innovatie, 2011).

The vulnerability of the agricultural sector to droughts depends on public and private adaptation. Eventually, the Deltaprogram will develop public adaptation strategies to secure the future freshwater supply to all economic sectors that are dependent on fresh water and thus also to the agricultural sector. Besides public adaptation, farmers are likely to take private adaptation measures since they are proactive agents who respond to changes in their environment (Crane, Roncoli *et al.*, 2011). The performance of the agricultural sector and the sector's vulnerability to drought depends on the adaptive behavior of individual farmers (Reidsma, Ewert *et al.*, 2010). In order for public adaptation to be successful, adaptation decision-making at the farm level and the consequences of these actions for the performance of the agricultural sector as a whole need to be well understood.

As we saw above, changes in the agricultural sector's drought vulnerability depends on the adaptive behaviour of many individual farmers. How does this process work? Farmers have to make production decisions in a drought risk context. In this study we adopt a psychological approach to investigate farmers' drought adaptation. The psychological approach to decision-making under risk is an alternative to the economic approach that has been frequently applied to assess the economic loss to the agricultural sector due to droughts (Iglesias, Garrido *et al.*, 2003; Dono and Mazzapicchio, 2010). The economic approach is based on four assumptions (1) perfectly rational agents, (2) the absence of interaction among agents (3) homogenous agents, and (4) focus on market equilibrium (Tesfatsion and Judd, 2006). However, in a risk context economic agents turn out to be less rational than initially thought. In such situations characterized by incomplete information they are more likely to make decisions based on an experiential way of thinking in which affect and emoting play an important role (Slovic, Finucane *et al.*, 2004). Adopting the psychological approach enables us to consider farmers as heterogeneous interacting agents that have incomplete information and that make decisions based on economic considerations as well as risk perception, as we observe in reality.

The agricultural sector is composed of many farmers who have different production characteristics, knowledge and experiences. In conditions of uncertainty, farmers interact and learn from each other. Interactions involving exchange of information on for example the probability of a drought event and successful adaptation strategies causes emergent phenomena on two different scales. At macro level, it causes the diffusion of adaptation strategies through the social network and it determines the vulnerability of the agricultural sector. In turn, information from the social network and information on the vulnerability of the sector feeds back into the decision-making of an individual farmer at micro-level through their expectations so that the decision-making of a farmer depends on that of others.

Because of these characteristics (heterogeneity of agents, interaction, emergent phenomena and feedback effects), the agricultural sector can be defined as a complex adaptive system (Tesfatsion and Judd, 2006). The link between adaptation on the individual scale and vulnerability on the macro scale remains a poorly understood topic for the social science research due to the complex adaptive character of economic systems (Kirman, 1992; Adger, Nigel *et al.*, 2005; Patt and Siebenhuner, 2005). Complex adaptive systems can be best studied with agent-based models (ABM). ABMs are actively applied to study farmers' behavior in several contexts (Balmann, 1997; Barreteau and Bousquet, 2000; Berger, 2001; Happe, Kellerman *et al.*, 2006; Valbuena, Verburg *et al.*, 2010; Schreinemachers and Berger, 2011; Le, Seidl *et al.*, 2012).

In this paper, we describe a conceptual model that forms the basis for an ABM of the adaptation process of the agricultural sector, using the ODD protocol (Polhill, Parker *et al.*, 2008; Grimm, Berger *et al.*, 2010). The purpose of the model is to link individual adaptation decision-making to consequences for the vulnerability of the agricultural sector at the macro level.

2. ODD MODEL DESCRIPTION

2.1 Overview

2.1.1 Model purpose

The purpose of the model is to explore how the adaptive behavior of farmers at the micro level affects the vulnerability of the agricultural sector to climate-induced uncertainty regarding water availability and quality. From a scientific perspective, it contributes to the scholarly literature by tracing the relationship between individual adaptation and sector vulnerability explicitly. From a policy perspective, the model helps to design public adaptation strategies to secure the freshwater supply in the future. The information generated with this modeling exercise could provide policy-makers with information on the private adaptation process that is useful for the design of public adaptation strategies that should be fine-tuned to private adaptation actions.

2.1.2 Theoretical and empirical background

We develop a conceptual model in order to investigate the relation between farmers' adaptive behavior and the consequences for the sector's vulnerability using an agent-based model see, Figure 1. This is a bottom-up model, in which agents-farmers exhibit adaptive behavior and through interactions give rise to the emergence of a certain level of vulnerability of the agricultural sector (Kellermann, Happe *et al.*, 2008).

Farmers operate in an environment consisting of the social and the biophysical sphere. Their decisions depend on and affect both of these environments. Models that incorporate the interaction between the social and biophysical environments are referred to as 'coupled human-natural system models' (Monticino, Acevedo *et al.*, 2007). The social environment consists of three components:

I. Other farms. Farmers connect to other farmers through the social network to which they belong (Valbuena, Verburg *et al.*, 2010). Due to interaction within the network, information and knowledge on droughts and adaptation strategies of other farmers becomes available and affects a farmer's decision-making. On the other hand, a farmer gives input to this network influencing the decision-making of others.
II. Input markets for labor, capital and land. Farmers buy production factors on input markets and compete for these resources with other farmers. Participation on these markets causes a flow of money from the farmers to the market in the form of payments for production factors. Besides a money flow, it causes a flow of inputs from the markets to the farmer.
III. Crop markets. Farmers sell their yield on the crop market. In turn for their crops, they receive revenue, depending on the crop price. We consider the crop market as exogenous because markets for agricultural commodities are international and therefore beyond the scope of this regional study. To include the effect of large-scale droughts on agricultural commodity prices, we will formulate several drought scenarios at different geographical scales translated in commodity prices and analyze the effects on the vulnerability of the regional agricultural sector.

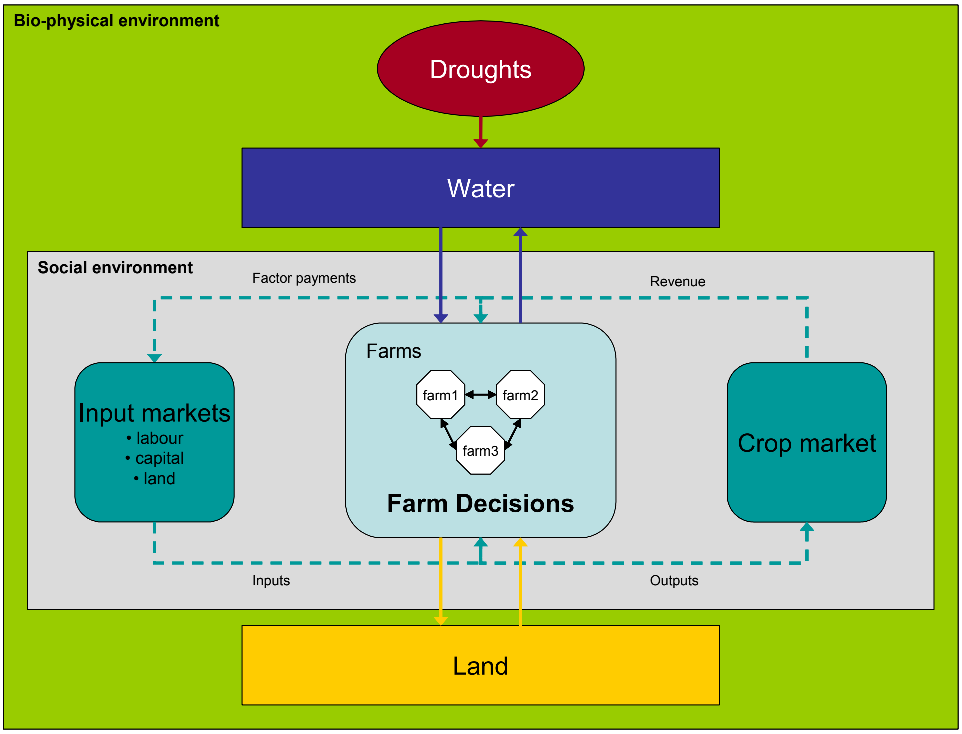

Figure 1 Conceptual model

The biophysical environment consists of two components:
I. Water. Crop production is dependent on water availability during the growing season. Meteorological conditions result in a given water availability and water quality. Water quantity and quality are exogenous model drivers. Eventually, we will investigate farmer's adaptation under several drought scenarios.
II. Land. Land properties like soil type, soil quality and the suitability for irrigation are important determinants of agricultural production. These land properties, together with other characteristics such as the field to which it belongs, the location of the field and past land prices form information for farmers that participate on land markets.

In this environment, individual farmers make decisions on their production activities. Their decision-making process in the model is based on several assumptions. Farmers operate in a drought risk context characterized by incomplete information; they do not have perfect information on the weather forecast, the available production techniques and costs and benefits of using those techniques. Furthermore, farmers are boundedly rational. Confronted with drought risk they are likely to make decisions based on affect and emotions rather than an analytic way of thinking in which they carefully weigh the costs and benefits of all decisions (Slovic, Finucane *et al.*, 2004). We chose this psychological approach as the basis to formulate agent decision rules, since it gives a more realistic description of how decisions are taken under risk than for example the pure neoclassical economic approach that assumes perfect information and perfectly rational agents. The model's decision-rules will be based on empirical data that we will gather using a survey among farm households.

2.1.3 Entities, state variables and scales

The model's agents are farmers, Figure 2. A farmer has the following characteristics: land, capital, crops, production function, risk perception, memory, knowledge on adaptation and he is part of a social network. Farmers' decisions depend on factors that are variable in space. Think for example about water availability, water quality, soil type, and about the social network which are all spatial explicit. On the other side, farmers' decisions produce spatial outcomes. Decisions affect cropping patterns and land-use (agriculture and other functions). The fact that many factors of the social environment and biophysical environment are dependent on space asks for a spatially explicit agent-based model. The model runs at the scale of a region. The landscape is divided into a grid of cells equal to 1 ha; this reduces the amount of required data since the spatial effects within the cell is ignored. Each cell has its own characteristics, including their farm-id (owner), field-id (each cell belongs to a field) water availability, water quality, soil type, land-use (crop), yield.

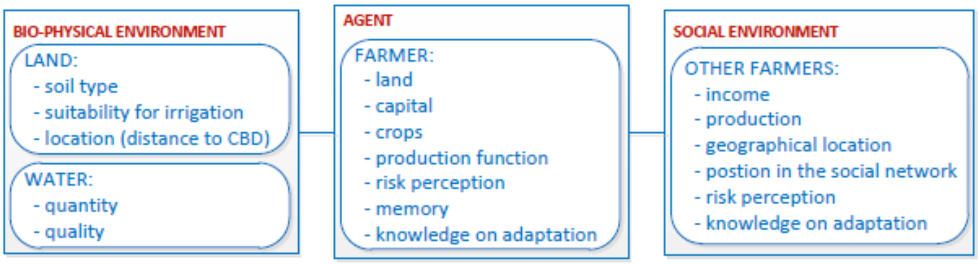

Figure 2 Model entities and state variables

2.1.4 Process overview and scheduling

The central process in the model is the agricultural production process of individual farmers. Each time-step, which represents a year, consists of several stages in which farmers take several production decisions. The conceptual model gives a clear static description of the components related to farmers' decision-making. To develop an agent-based model of drought adaptation we need to understand two other matters: 1) the dynamics of a farmer's production process (Balmann, 1997; Kellermann, Happe *et al.*, 2008) and 2) the drought adaptation options that are available at each stage of the production process (Blom, Paulissen *et al.*, 2008). In order to get a better understanding of these issues, we describe the sequence of production decisions a farmer has to make during a growing season and his options for adaptation.

During a year, agricultural activities can be divided into four subsequent periods with clusters of activities; these are the preparation, cultivation, harvest and post-harvest period (Nhemachena and Hassan, 2007). The preparation period concerns the period after harvesting and before planting. Farmers' activities mainly focus on the preparation of land for the coming season, for example plowing. In this period, a farmer makes two important decisions:

I. (Dis)investment in land. He bases these decisions mainly on the results of last years, his current assets, the financial constraints and his expectation about the future (Balmann, 1997). Considering the land decision, there exist two types of markets: a market to buy or sell land and a market to rent or let land. Transactions on these markets may cause changes in land-use. The supply on the land market depends on the land that becomes available for sale from farmers that exit the sector or from farmers that do not renew their renting contracts. Demand for land depends on the credit worthiness of farmers, their expectation about the future of their farm, the price of the location and quality of the land. A farmer might adapt to drought by acquiring land that is suitable for irrigation or that is located in an area where droughts have less impact on crop production due to local conditions. A farmer can also decide to sell or let land that has bad local conditions or that is unsuitable for irrigation.
II. (Dis)invest in capital. The capital investment decision concerns the purchase of machinery and equipment required for crop production. There are two categories of investments in farm capital: 1) investments in replacement of existing capital and 2) investments in additional capital. Investments in replacement capital depend on the economic depreciation of the existing capital. Investments in additional capital depend on the saved profits of previous years and the expectation about the future of their farm. There is a special type of investment, the investment in innovations. In agriculture, technical improvements are largely process innovations such as irrigation technology, fertilizer, tractors and pesticides, but product innovations also exist such as new crop varieties. A farmer can adapt to drought through the investment in for example irrigation equipment or rain basins. This could also be the investment in innovations like new reverse osmosis technology to desalinate water.

The cultivation period consists of the planting of crops and the cultivation activities like weed control and irrigation. During this period, a farmer has to make three decisions:

I. A farmer has to decide which crop he is going to grow on which land, when he is going to sow or plant the crop and how he is going to produce it. A farmer does not always have to take a decision on which crop he will grow the coming period, some crops have a more permanent character and are not removed during the harvest, for example crops from which only the fruit is harvested. The crop decision depends on many factors:
    a. Soil type and quality.
    b. The crop rotation scheme. Farmers frequently use crop rotation, to prevent decreasing soil fertility and to avoid pests. However, not all farmers use rotation schemes.
    c. A farmer's expectations on for example the weather and crop margins.
    d. A farmer's knowledge about the crops characteristics, for example their water use and salt tolerance.
    e. The availability of technology, like irrigation. Some crops need specific treatment that requires the possession of particular technology.

   As a response to drought, a farmer can choose to use crops that are less water demanding or that are more salt tolerant.
II. After deciding which crop they are going to grow, they have to decide when they are going to sow or plant the crop. Crops need to be planted in a specific period, but within this period, there is some flexibility. This decision mainly depends on the weather, to wet or dry conditions can affect the crop during the first phase of the growth-stage so farmer can adapt to too dry condition by delaying the sowing or planting date.
III. Finally, a farmer has to decide how he is going to grow/cultivate the crop. This decision concerns a farmer's activities during the crop growth-stage.

These activities concern weed control, soil treatment, the use of pesticides, fertilizer and irrigation. The choice of inputs depends on the crop characteristics and on the growing conditions that affect the productivity. Growing conditions concern the weather and the outbreak of pests and diseases.

During the harvest period, farmers harvest the crops. In some cases, the crop is completely removed from the land like in the case of potatoes. In other cases, only the fruit is harvested. An important decision a farmer has to take in this period is when to harvest; the weather and the crop maturity are two important determinants of this decision. The weather forecast as well as a farmer's expectations plays an important role, farmers can adapt to droughts by delaying or moving up the harvest date. The harvest results in a crop yield expressed in kg/ha. In the post-harvest period, the yield is sold on the market. Individual farmers do not have much influence on the price formation because they operate on a competitive market with many buyers and sellers. Important sale determinants are the access to markets and the market prices. This results in the crop income of a farmer. Besides income of crop production, a farmer can create income from other agricultural or non-agricultural activities and he can have income from other sources such as subsidies. Based on the total income and the fixed and variable production costs a farmer is facing profits or losses. At the end of the year, a farmer makes up his balance sheet. Insolvency forces the farmer to exit the sector. Negative cash flows will reduce a farmer's future credit availability. Another aspect in the continuation decision is the farmer's age together with the presence of a successor. Based on the process overview description we designed a time-sequence diagram that serves as the basic information for the model flow of the agent-based model, Figure 3. It represents 1) initialization and 2) sequence of events in one time step. In the initialization phase the model assigns land attributes, farmers' attributes and connection between farmers. All other processes are repeated each time step.

2.2 Design concepts

2.2.1 Individual decision-making

The objective of farmers in making their decisions is to satisfy a particular need; in the first place, they want to get satisfied with their level of income based on their income aspiration level. In the model, we apply the Consumat Approach (Jager and Janssen, 2003) to define agents' decision-making rules since this theory incorporates interaction as an important determinant of individual decision-making. The approach originates from consumer research and has been applied to study diffusion of innovations and to study climate change adaptation with the use of ABMs (Brouwers and Verhagen, 2003; Acosta-Michlik and Espaldon, 2008). According to the Consumat approach farmers follow a specific cognitive process for decision-making depending on their drought risk perception, the level of satisfaction with their income, the uncertainty on the effectiveness of adaptation strategies, the influence from the social network and the cognitive effort to make decisions (Jager and Janssen, 2003). Based on these factors this theory distinguishes six cognitive processes for decision-making: 1) repetition, 2) imitation, 3) satisficing, 4) improving, 5) social comparison and 6) deliberation.

Agents with a high risk perception base their decisions on the behavior of others, for example through social comparison or imitation. In contrary, agents with a low risk perception are more likely to make decisions individually for example through repetition, improving, satisficing or deliberation. The more an agent is satisfied,

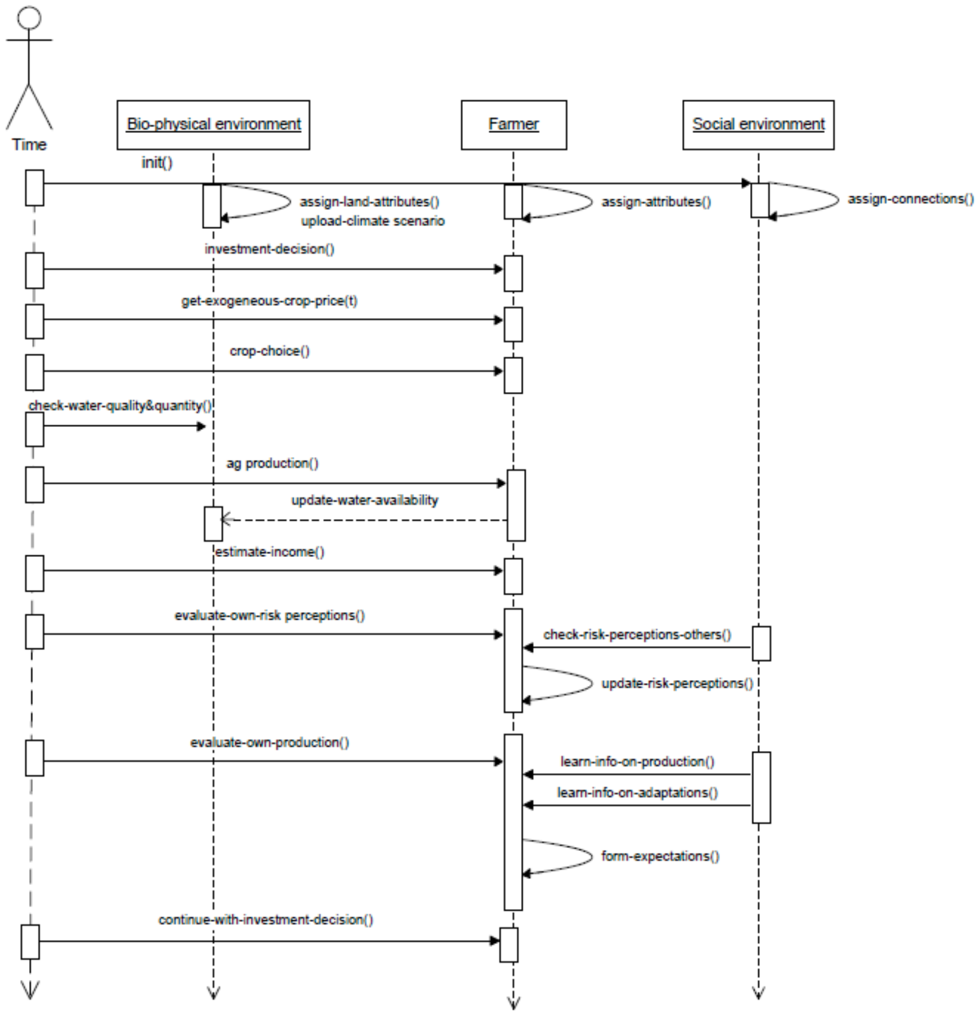

Figure 3 Process overview and scheduling

the more he will rely on automated actions like repetition and imitation; they are less willing to invest cognitive effort to change their behavior. In contrary, agents that are not satisfied engage in reasoned action, strategies that require more cognitive effort, for example in social comparison, satisficing or deliberation.

In the ABM, the agent's decision-rules are based on the cognitive strategy that they follow. In the case of social comparison, a farmer compares his past behavior with that of agents having similar abilities and makes the decisions, which yield the maximum level of need satisfaction. Imitation means that farmers imitate the decisions of a farmer in their social network, without any comparison with other farmers. Farmers that follow the cognitive process improving determine the consequences of decisions one by one and select the first decision that improves his level of income satisfaction. Satisficing means that an agent determines the consequences of decisions one by one and selects the first decision that satisfies his needs. For deliberation, a farmer examines the consequences of all possible decisions given a fixed time horizon in order to maximize their level of need satisfaction.

2.2.2 Learning and prediction

Agents' cognition constantly evolves over time: farmers adapt to changes in their biophysical environment and to changes in information from sources within their social environment. Each year, farmers form expectations based on their own experience and the experience of other farmers in their social network. Risk perception and level of satisfaction change over time depending on experiences and interaction with other agents, so that agents might use another cognitive process to make a decision at a later point in time. For example, an agent initially has a medium high satisfaction level and a low risk perception. Therefore, it makes a decision based on improving; it determines the consequences of the alternatives one by one and selects the first decision that improves his needs. In the next period, an agent has, due to his decision in the previous period, a high level of satisfaction and a low risk perception. Therefore, he will make a decision based on repetition in this period.

2.2.3 Individual sensing

Information on the characteristics of the biophysical environment is public to all farmers. Information from other farmers, concerning their income, aspiration level, knowledge on adaptation strategies and expectations for the future remains limited to farmers that belong to a specific social network. The model is implemented on a regional scale; the spatial scale for sensing does not restrict farmers.

2.2.4 Interaction

Farmers interact directly on land markets and within their social network. Farmer's that do not belong to the same social network interact indirectly through the biophysical environment. In that case, farmers are only able to observe the spatial characteristics of the fields that belong to the other farmer.

2.2.5 Collectives

The farmers belong to a social network. Farmers influence the information available in the social network depending if they are actively contributing to the social network by sending information and whether they have social influence. On the other hand, farmer's decisions are affected by the information available from the social network, depending on how sensitive they are for social influence.

2.2.6 Heterogeneity

Farmers are heterogeneous in few dimensions. They have different production characteristics (for example the location of the homestead, the amount of land, capital and labor). They differ in the cognitive process that they use to make decisions, in their income aspiration level, level of satisfaction, risk attitudes, drought risk perception, to which social network they belong, their social influence and their sensitivity for social influence.

2.2.7 Stochasticity

The water availability and water quality are assumed partly random. Each climate scenario that we analyze consists of a particular water availability and water quality distribution. Depending on the selected climate scenario, the model draws a specific water availability and water quality. The chance of a particular water quantity and quality is dependent on the selected distributions.

2.2.8 Observation

The vulnerability of the agricultural sector (annual loss of harvest, % of farmers bankrupt and on near-zero profit margin), the diffusion of adaptation strategies (% of adopters) and land-use patterns (2D maps, quantity of land under certain agricultural activity/technology) emerge as result of farmer's adaptation and interaction in social networks and markets.

2.3 Details

The model is currently being implemented in Netlogo (Wilensky, 1999). We are simultaneously developing a survey to parameterize farmers' behavior and the ABM. Currently we work with a stylized model with arbitrary parameterization of the landscape and behavior at the initialization stage. A field is set up from individual cells that are equal to 1 ha. A patch is linked to a field through the fact that each patch has a field-id. Therefore, the size of the field is dependent on the number of patches with a specific field-id. Each farmer owns two fields with a particular field-id. Farmer and fields are linked through the fact that each patch has a farm-id. Each field has a land-use system (lus), this is a combination of a crop (sunflower, grass, barley or Brussels sprouts), crop productivity (kg/ha) (under optimal growing conditions), crop price and water consumption (liter/kg). Water consumption can be regarded as the requirement for optimal crop growth. The model flow follows the sub-models that are described in details in sections 2.1.2 and 2.1.4.

3. FUTURE WORK

This paper describes an ABM to study the effects of individual farmers' adaptation decisions using ODD protocol. The model development is a work in progress and much still needs to be done especially on collection data for model calibration and validation. Specifically, the model needs empirical data:

1. on current land-use and farm characteristics to set up the model environment
2. to parameterize the agents' decision-rules
3. on drought resistance and salt tolerance of crops and crop prices
4. on water availability and quality to generate droughts scenario's

Land-use data, farm data, crop data and water data are partly available from the CBS Statline databases and from the existing model called Agricom. This agronomic model calculates crop damages for several water availability and salt concentration scenarios for several land-uses and soil types in the Netherlands. The missing data on farm characteristics and the data to parameterize the agents' decision-rules will be collected using a survey among farmers. Besides socio-demographic data, this survey includes items on a farmer's motivation to adopt adaptation strategies, their innovativeness and their position and participation in social networks.

The model will be applied to a case study area in the Southwest Netherlands. When the first data is integrated in the model, we will study the following research questions:

1. What is the pattern of adaptation strategy diffusion under different drought scenarios?
2. How does the vulnerability of the system change under different drought scenarios?

We look forward to discuss our first theoretical results during the conference.

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