Online Resources

Modeling the decline of labor-sharing in adverse environments

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Objective, design, and details: the ODD protocol to describe agent-based models

In this section we describe the agent-based model, following the standard protocol to describe agent-based and individual-based models by (Grimm et al. 2006).

Purpose

The purpose of the model is to understand the influence of water scarcity, water variability, and water-related uncertainty on the structure and robustness of the labor-sharing networks in agricultural communities in the semi-desert region of North Chile.

Entities and State variables

Agents
The agents in the model are households of farmers in an agricultural community. The attributes of each household are the accumulated wealth, the productivity of the land, the valuation of outcome (gain-seeker or loss-averse) and the reputation.
Contracts are links that connect two households that are created every time-step (ticks) when households set labor-sharing agreements. Contract links die after the final decisions are made. Families have friendship links among them, which are represented as direct links in Netlogo. The attributes of these links are the level of trust and the image that one household has about other.

State variables

The state of a household is defined by its wealth, obtained from wages and agricultural production (H) that depends on water availability at time t (x_t), Amount of land (A), labor (L), and the help of others in the community. Each household value maintains the level of reputation that is defined by the trust others in the community have in them. Trust of each other depends on fulfillment of the agreements to share labor.

Environment
The environment is driven by water availability that changes over time according to the probability of good and bad years, and the temporal correlation between events. The productivity of the land is different for each household. Water availability and land productivity influence agricultural yield households can obtain in a year. Wealth is a function of agricultural production and wages obtained when households consider working outside the community.

Design concepts

Theoretical and empirical background
Prospect theory (PT) and Expected Utility (EU) are used to define the expectations. PT differ from EU by including detail mechanisms to define risk behavior and the perception of gain and losses.

Interactions
Households interact with each other by establishing agreements to share labor under the uncertainty about how much water will be availability for farming. After the rains fall, these agreements are updated and the decisions are redefined under the uncertainty about others fulfilling the agreement.

Stochasticity
The availability of water in each time step is drawn from an auto-correlated conditional binomial probability. This probability is defined by the average water availability and the temporal correlation.

Observation
Households kept track of previous direct interactions with others to define how much they trust others in the community. They also observe the interactions of others by calculating the reputation of other households.
We recorded the total number of fulfilled agreements (CC) and defections (CD) over a period of 100 time steps, as well as the mean level of wealth, trust and reputation of the community over the period of simulation.

Emergence
From the interactions between households and the number of fulfilled contracts in each time step, a network of labor-sharing contracts emerges.

Learning and adaptation
Households change their level of trust on others based on the comparison between the agreement and the final decision. This information then is used to calculate the reputation of each household and the image probability. The image represents the expectation that a household would fulfill a labor-sharing agreement.

Sensing
In order to define the agreements and the final decisions, households obtain information about the productivity of the land, and the reputation and trustworthiness of others. They also have information about the probability of a good or a dry spell.

Describing Human behavior component using the MoHub framework

We complement the description of the model in the ODD protocol by providing a detailed description of the internal decision-making process of the households using the MoHub framework presented in (Schlüter et al. 2017). The framework, presented in figure 4 of this document, helps to decompose the decision-making process into what comes in (perception), what goes out (behavior), and what happens in between ('rules' and representations that lead to the selection and execution of a behavior). The outer box represents the social and biophysical environment and thereby the decision context of a household. The household itself is represented by the structural elements (stated and perceived behavioral options) and processes involved in decision-making. The process that leads to a decision is defined by the evaluation, the behavioral options, and the selection method, and the evaluation of the environmental components

Perception
Households obtain information about the potential productivity of the land, the expectation of water availability, and the the result of the outcome with other households. They also obtain information about the reputation of others.

Evaluation
Households evaluate if they received help from others, by comparing the agreement made before the rainy season and the final decision made after the rainy season. They score each interaction with other households. This score affect the trustworthiness and the reputation of each household.

Learning
The evaluation of the agreement and the final decision provides information to the agents, who then use it to learn about how much to trust other households. This information is critical for defining the next round of agreements.

State
Each household has a finite amount of time/labor that is designated to work on its own personal farm, to share labor with others, and to work outside the community. Households evaluate the expected gains and losses according to their risk behavior and the reference point.

Perceived behavioral options
Before the households know about the availability of water in a single time step, they have two options: They can stay in the community work in their farm and cooperate with other households, or they can decide to leave the community, engage in working off-farm and not designate time to help others others. After they obtain information about the availability of water,

each household can individually change its decisions to fulfill the agreement or not. This decision, however, is made under uncertainty about the other family's decision to stay. The perception of social risk is defined by the image probability of friendship.

Selection process
Households choose the alternative that maximizes expected gains and minimize losses.

Behavior
The selected decision by a household influences the yield, wages, and finally the utility obtained by the household and the other households with whom an agreement to help each other was set.

Socio-environmental context
The environment of the community is driven by the availability of water that affects the entire community equally, but the productivity of the land varies between households. Households have the possibility to work off-farm and receive wages income.

Figure 4. Graphical representation of the household decision-making process. Red text is used to highlight the differences of Prospect Theory from Expected Utility.

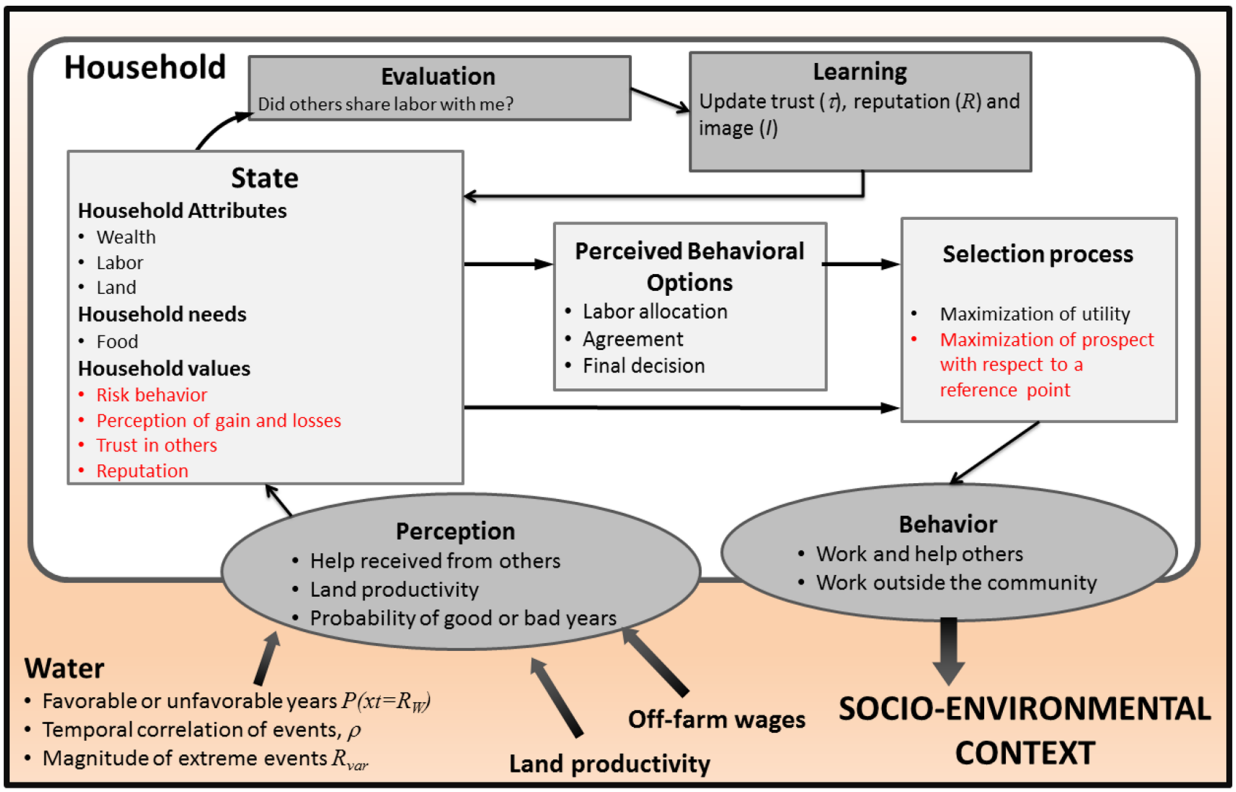

Table 1. Parameter names, symbols, and values used for the simulations shown in the results section.

Parameter name	Symbol	Value	Units
Community size	N	*40*	Households
Land	A	*[1-2]*	Area
Off-farm wage	W	*[1-4]*	$/ Labor time
Available water	x	$[R_W, R_D]$	[mm3/Area*year]
Factor of cooperation	φ	*1.5*	[yield/mm3*labor]
Harvest	H	*[]*	[yield/year]
Wet year	R_W	$1+ R_{var}$	[mm3/year]
Dry year	R_D	$1 - R_{var}$	[mm3/year]
Magnitude variability	R_{var}	*[0-0.8]*	[mm3/year]
Total household labor	L	*1*	Labor time
Own-farm labor	L_H	$L - L_W - L_C$	Labor time
Off-farm labor	L_W	*0.2*	Labor time
Shared labor	L_C	*0.2*	Labor time
Temporal correlation	ρ	*[0,0.8]*	-
Climatic risk	π	$P(x_t=R_W\|\rho)$	-
Risk behavior parameter	λ	*[-1.5, -0.5, 1]*	-
Risk behavior parameter	a	*[0.5,1,1.5]*	-
Probability of a good year	$P(x=R_W)$	*[0.1,0.8]*	-
Trust	τ	*[0-1]*	-
Reputation	R	*[0-1]*	-
Trust decay	μ	*0.3*	-
Importance of personal interactions	ε	*0.5*	-