Common ABM concepts represented in the model

The feedback between distant places is the primary feature of TeleABM. To follow the ODD+D protocol, we still document the following properties even though some concepts are not used in this paper.

Emergence

Farmer agents' land-use behaviors are expected to vary when their characteristics are initialized differently, the crop subsidy changes, and by the trading/climate scenarios. The expansion of rice paddy in the receiving is expected to emerge as well as the expansion of soybean-corn in the sending system.

Adaptation

Farmer agents do not change their decision-making rules. However, they adjust their land-use behaviors according to the crop price, profit, labor, previous land use, and other factors.

Objectives

Farmer agents in both systems try to maximize the suitability of the land cells in their property.

Learning

Farmer agents in the two systems update the crop profit every year. They also learn from their neighbors about the crop profit and use it to decide next year's land-use decision, if they do not grow the crop at current year.

Fitness

No survival fitness is included in the model.

Prediction

Farmer agents are not able to predict accurate crop price for next time step.

Sensing

Farmer agents can sense the crop profit of neighbour agents if they themselves do not grow this crop.

Interaction

Direct interactions occur between farmer agents and local trade agents. Direct interactions also happen between neighbour agents from observing each other and affecting the landscape (e.g., only when a neighbouring cell is rice paddy one can change it to rice

paddy). Indirect interactions occur between farmer agents in the sending and receiving systems through international trade agents. Farmer agents also interact with the environment through land-use decisions and management.

Stochasticity

Farmer agents have individual variation in attributes and decision-making parameters, which are drawn from survey data and set as statistical distribution. Furthermore, noises are added to crop management (e.g. a random number is added to fertilizer input and yield) and crop price (e.g. the crop price sensed by farmer agents have a small random value).

Collectives

The crop production from individual farmer agents is aggregated at the end of each time step, and enters the international trade agent. The crop price generated by the international trade agent later affects the individual land-use changes in both systems. Government agent also implements certain policies by reviewing the aggregated land-use results.

Heterogeneity

Heterogeneity is represented by farmer agents' properties, such as farm size and education. It is also determined by varying certain decision-making features, such as pro-diversifying in the sending system.

Observation

At each time step, land uses are recorded at each farmer agent level, as well as their capital and environmental usage (e.g. fertilizer use, yield, water usage).

Path dependence

Land-use decision of cell i at step t is affected by the land use of this cell at previous steps. The influence comes from (1) soybean farmer agent's knowledge of different crops, (2) land-use history that affects current crop choice and yield, (3) neighbours' land-use conversions from and to rice paddy can affect the possibility of agent's rice paddy decisions.

Details

Initialization

The initialization includes three parts:

Users set up global parameters: users determine which system(s) to run simulation on, the scenario of crop prices, and number of initial farmer agents and vision.

- static crop price: the model reads crop price written by users at the panel, and will stay the same over the simulation time steps
- dynamic crop price: the model reads files that include crop price at every year
- telecoupling feature: the model has sending and receiving systems, and exchange price information during simulation.

The model reads configure files and maps to initialize land cells:

- crop land-use maps from remote sensing data
- empirical crop suitability map
- empirical or hypothetical soil map

The model initializes agents and their characteristics:

- initialize parameters for each system, such as the range of production cost
- several attributes of agents (e.g. capital, gender ratio, education) are initialized based on weighted or normal distribution drawn on statistical distribution from survey data and other sources.

Input data

TeleABM uses three types of input data, which also corresponds to three initialization steps.

Supplementary Table 2: Input data of TeleABM

Input file	Function
Parameter setting	sending system representation receiving system representation number of initial farmer agents in sending system number of initial farmer agents in receiving system price of crops (soybean, corn, rice, cotton): if >0, static price, if<0, use dynamic price or use telecoupling price
Bio-physical data	land-use maps (classified MODIS images(2005 and 2010) and Landsat images (2000, 2006, 2011, 2016, as a verification source) of Gannan, Heilongjiang, and PRODES data (2004-2014) of Sinop, MT) temperature and precipitation map (empirical data, such as maps of annual accumulated temperature above 10°C and maps of precipitation of Heilongjiang) maps of soil types maps of elevation and slope

Socio-economic scenario	text files contain annual price of crops different settings of tariff maps of distance to urban and roads

Submodels

Ecological model. In this model (LandCell class in the receiving system), yield of crops (converted to land cell spatial unit from per ha) is a function of fertilizer, precipitation, and temperature, based on relationships found in literature. However, in this version, we do not include the crop yield response to fertilizer use in the receiving system. Crop yield is a constant value using the survey average (i.e., soybean 2,008 kg/ha, corn yield 9,597 kg/ha, and rice 8,112 kg/ha). In the sending system, the parameterization of each crop yield is given based on experts' opinion (Supplementary Table 3). For instance, if a cell is used as soybean-corn, the soybean yield is 3,007.2*90% kg/ha and the corn yield is 4,120*100% kg/ha.

Supplementary Table 3: Average crop yields to each land use type in Sinop, MT, Brazil

crop	average yield (kg/ha)	land use	parameter (%)
soybean	3007.2	single soybean	105
		soybean-corn	95
		soybean-cotton	95
corn	4120.0	soybean-corn	100
cotton	3346.2	single cotton	105
		soybean-cotton	95