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Supplementary Information

Multi-Agent Modeling and Simulation of Farmland Use Change in A Farming–Pastoral Zone: A Case Study of Qianjingou Town in Inner Mongolia, China. *Sustainability* 2015, *7*, 14802-14833

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Supplementary Materials 1

We listed the full edition of ODD + D protocol which is used to describe our farmland use change model. Here, we answered the 52 guiding questions in detail separately.

1. Overview

1.1. Purpose

1.1.1. What is the Purpose of the Study?

This model has been developed to simulate the effects of farmers' livelihood behaviors on farmland use change in a farming-pastoral zone and the effects of land quality on the farmer's land use decisions.

The household farmland use behavior was influenced by the coupled human-nature systems. So the purpose of the model is to understand that under the constraints of endogenous factors (the family structures and economic development) and exogenous factors (government policies and natural factors), what the rules of the farmland use change behavior of different types of households are, *i.e.*, whether to farm or not? If to farm, how many farmland plots do households plant and where do they plant? Through simulation, we can predict system-level properties of the household farmland use behavior as an emergent product. The changing trend of farmland use states (planted by the owner, rented to other households and abandoned by the owner), farmland aggregation degree and the number of different types of households in the study area can be observed in the next 30 years.

1.1.2. For Whom is the Model Designed?

The model aims at exploring the management strategies that take sustainable rural livelihoods and sustainable farmland use into account, and provides decision support for managers to maintain the sustainability of human-nature systems.

1.2. Entities, State Variables and Scales

1.2.1. What Kinds of Entities are in the Model?

In the model, entities are compromised by agents (individuals, households, household group and government), spatial units (grid cells), environments (NPP, road, slope and relief amplitude) and collectives (list of agents, list of land plots, *et al.*).

1.2.2. By What Attributes (*i.e.*, State Variables and Parameters) are These Entities Characterised?

The state variables and parameters of entities will be listed as follows in Table S2-S7. In order to simplify these descriptions, we only listed the main state variables.

The government's Grain Subsidy Policy has had an effect on household livelihoods and their farmland use modes. The households in this study area received the same governmental policies. Therefore, there is only one government agent in this model, and there are no x or y coordinate information.

1.2.3. What are the Exogenous Factors/Drivers of the Model?

The exogenous factors of the model include government policies and natural factors (land use cover, accessibility of road network, slope, relief amplitude and NPP).

1.2.4. If Applicable, How is Space Included in the Model?

The model is built based on real landscapes. We overlap the layers of LUCC, NPP, slope, relief amplitude and accessibility of road network according to their projected coordinates.

1.2.5. What are the Temporal and Spatial Resolutions and Extents of the Model?

In the model, 1 time step represents 1 year (the time resolution), and the length of period is 30 years. In China's mainland, the rural land property rights institution is a family-contract responsibility system, and the household is the basic unit of land management. This responsibility system remained unchanged for 30 years, so our simulated length of period is 30 years.

The study area is Qianjingou Town, and it covers an area of 600.11 km^2. The spatial resolution is 96 m × 96 m, *i.e.*, the area of a grid cell (About why we set 96 m × 96 m as spatial resolution, see Section 4.3.2).

1.3. Process Overview and Scheduling

What Entity does What, and in What Order?

Figure S1 shows the discrete events mechanism when the model is running at time t + 1. After time t is finished, the age of the individual agents is increased by 1 year, and their occupation states are updated (according to Figure 6. for detail, see Section "Descriptions of Submodels" (1)). Changing the family members' occupation states changes the household type. So after individuals change their occupation states, we need to determine the type of each household (for detail, see Section "Descriptions of Submodels" (2)). Based on the relationships between household livelihood and farmland use behavior in different groups (for detail, see Section "Descriptions of Submodels" (4)), we obtained the household farmland use decisions rules (no change, expanding scale, or reducing scale). Some households hired farmland while others rented out farmland, so we simulated the land exchanging process base on questionnaires. In our study, there are no migrant farmers, and land exchanging carries out between local households. About the land renting in and hiring process, two questions needed to be answered: how many plots can each household plant? Which plots do households rent out, abandon or hire? To answer the first question, we obtained the maximum plots that each agricultural laborer can plant. Here, we use "k" to refer to this index, which was calculated from the questionnaires, and this index reflects the maximum number of farmland plots that each agricultural labor forces can plant. This is only the maximum capacity of each agricultural labor force. In fact, not every agricultural labor force plants k plots. Considering the planting capacity of each agricultural labor force, we introduce K into our model to reflect the real world. If a household has m agricultural laborers, the maximum number of farmland plots this household can plant is m*k. If the number of farmland plots divided by m is greater than k, households will reduce the scale of their planting; alternatively, they will consider increasing the extent of their planting scales. To answer the second question, we need to calculate the I_{total} value of each plot planted by each household (for detail, see Section "Descriptions of Submodels" (3)), and rank these plots according to their I_{total} value in ascending order. The households prefer to rent out or abandon the plots with low I_{total} value, while hire the plots with high I_{total} value. When the plots that were rented out by some households were not be hired by other households, they would be abandoned, and the land renting in and hiring process was failed; otherwise, the plots would be farmed by other households, and the land renting in and hiring process was successful.

Because of agricultural mechanization popularity in the study area, one agricultural laborer can plant 10 plots (9.3 hectares), *i.e.*, k is equal to 10. To illustrate this process in detail, we describe 5 types of households as follows. For ease of description, we use "p" to refer to the total number of farmland plots each household owns, and "q" to refer to the number of agricultural labor forces.

(1) Subsidy-dependent households: 100% of households do not plant farmland.
(2) Pure-farming households: Check whether p/q is less than 10. If so, 72% of households hire farmland; they do not rent out farmland. For households who have renting in farmland decisions, they will hire q × (10 − p/q) plots.
(3) Part-farming households: Check whether p/q is less than 10. If so, 54% of households will hire q × (10 − p/q) plots; alternatively, 28% of households will decrease planting plots by q × (10 − p/q) plots.
(4) Non-farming households: Check whether p/q is less than 10. If so, 44% of households will hire q × (10 − p/q) plots; alternatively, 52% of households will decrease planting plots by q × (10 − p/q) plots.
(5) Pure-outworking households: 100% of households will rent out or abandon all of their farmland plots.

Finally, we calculated the family income of each household (including agricultural production, wage/salary, renting land income and payments from the Grain for Subsidy Policy), and spatially displayed the plot use states. At this point, time t + 1 ended, and the discrete events mechanism was terminated.

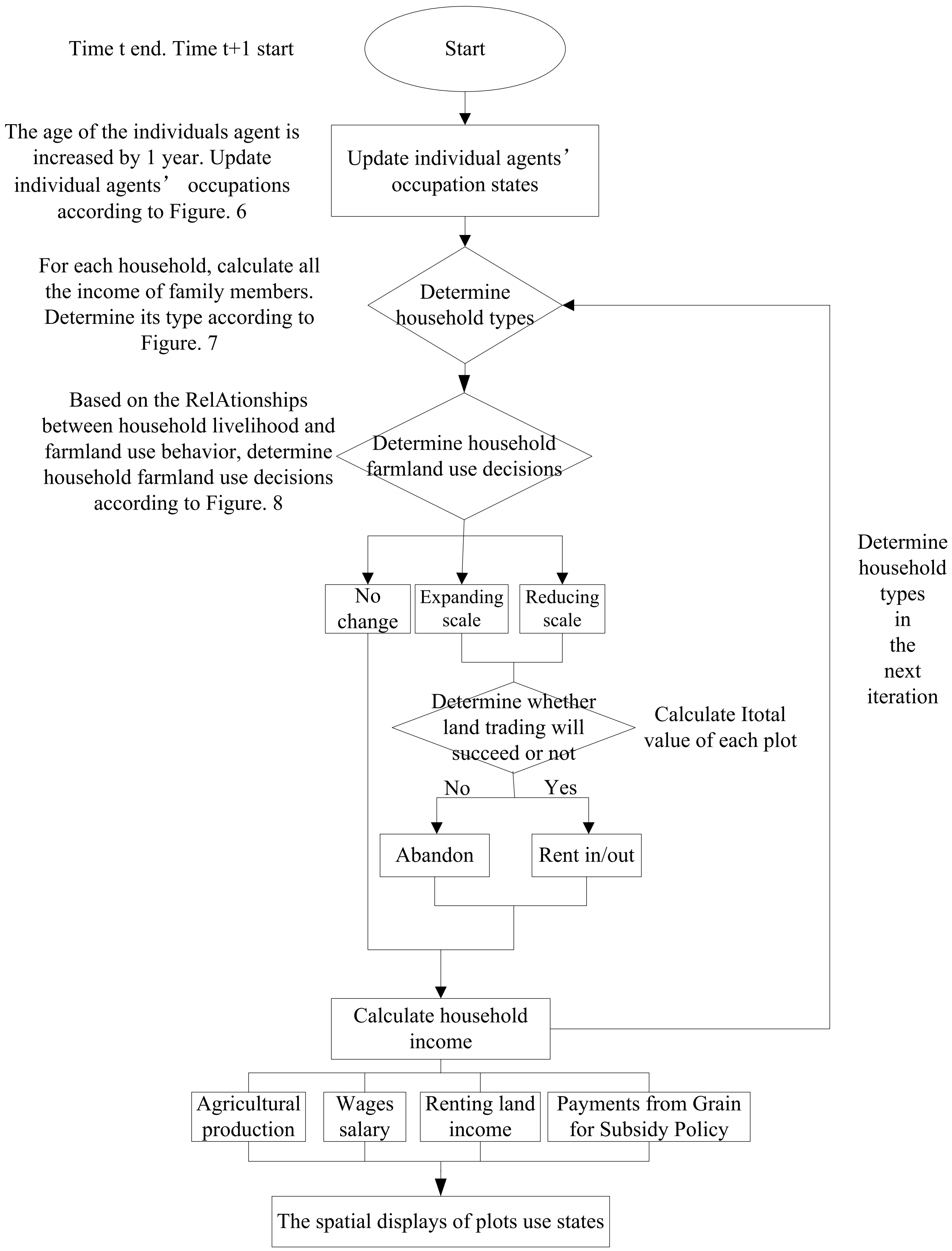

Figure S1. Flow chart of the mechanisms of discrete events when model is running at time t + 1.

2. Design Concepts

2.1. Theoretical and Empirical Background

2.1.1. Which General Concepts, Theories or Hypotheses are underlying the Model's Design at the System Level or at the Level(s) of the Submodel(s) (Apart from the Decision Model)? What is the Link to Complexity and the Purpose of the Model?

a. General concept: We want to use "farmland area per capita" index to show the changing trend of farmland management area for each household. To facilitate analysis, we proposed "farmland aggregation degree (FAD)" index to indicate the farmland area increase or decrease cropped by each individual on each household basis, calculated as

$$FAD = \frac{AREA_{household}}{N_{member} \times AREA_{individual\_0}} \tag{S1}$$

where *FAD* refers to the farmland aggregation degree; $AREA_{household}$ refers to the farmland area managed by each household; N_{member} refers to family size of each household; $AREA_{individual\_0}$ refers to the farmland area of each person allocated by the government at the initialization of the model, *i.e.*, 0.9 hectare. $FAD = 1$, indicates that farmland per capita in this household is unchanged compared to the initialized time (*i.e.*, 0.9 hectare); $FAD = 0$ indicates that all farmland is rented out or abandoned by the owners, and $0 < FAD < 1$ refers to households that rented out or abandoned part of their farmland. $FAD > 1$ indicates that, households expanded their planting scales. The greater the *FAD* value is, the more farmland area managed by the household.

We set five intervals of *FAD*, *i.e.*, zero *FAD* ($FAD = 0$), low *FAD* ($0 < FAD \leq 1$), middle *FAD* ($1 < FAD \leq 3$), high *FAD* ($3 < FAD \leq 6$) and super high *FAD* ($FAD > 6$). Zero *FAD* refers to that all farmland is rented out or abandoned by the owners, and low *FAD* refers to households that rented out or abandoned part of their farmland. Middle *FAD*, high *FAD* and super high *FAD* refer to three levels that households expanded their planting scales. *FAD* can reflect the states of the farmland management scales and farmland management right redistributions.

At the initialization of the model, one individual was assigned to 0.9 hectare of farmland. If there are "N" family members in a household, a household will have 0.9 × N area of farmland to plant. At a later time, farmland was rented or abandoned, and the area of farmland planted by each household will changed simultaneously. We can determine whether the households expand planting scales or reduce them according to the value of *FAD*.

b. Hypotheses: there are 4 hypotheses in our study. (i) During the model running time, farmland was not reclaimed, and there was no new farmland generated. The households only plant crops on the original farmland plots; (ii) During the simulated 30 years, the running rules of the model remain unchanged. The model parameters of farmland area per capita, migrant work salary, prices of naked oats, the prices of land rent and the yield of farmland are fixed; (iii) The land renting in and hiring process is carried out between local households, and it is not influenced by migrant farmers. In our study, we use I_{total} value to refer to the quality of plots. The households prefer to rent out or abandon the plots with low I_{total} value, while hire the plots with high I_{total} value. When the plots that were rented out by some households were not be hired by other households, they would be abandoned. (iv) According to questionnaires analysis, we set the maximum plots that each agricultural laborer can plant (we use “k” to refer to this index). When the number of farmland plots planted by per agricultural labor forces is greater than k, the households will reduce the scale of their planting.

2.1.2. On what Assumptions Is/Are the Agents’ Decision Model(s) Based?

The agents’ decision models are based on the assumptions that, households in the same group have the same farmland use behaviors. The transitions of individuals’ occupation states follow specific mechanisms (for detail, see Section “Descriptions of Submodels” (1)).

2.1.3. Why Is/Are Certain Decision Model(s) Chosen?

We use the surveyed data to analyze the characteristics of individuals and households in the real-world. Using a probability method to get the model running mechanisms can effectively describe agents’ characteristics from an overall view.

2.1.4. If the Model/Submodel (e.g., the Decision Model) is Based on Empirical Data, Where do the Data Come from?

Our model is based on empirical data, and this data is collected from first-hand questionnaire surveys on the spot.

2.1.5. At Which Level of Aggregation were the Data Available?

The data is available at yearly aggregation level.

2.2. Individual Decision Making

2.2.1. What are the Subjects and Objects of the Decision-Making? On Which Level of Aggregation is Decision-Making Modelled? Are Multiple Levels Of Decision Making Included?

Four types of agents were used to model the farmland use change system, *i.e.*, individual agent, rural household (shortened to household) agent, rural household group agent and government agent. The decision-making includes multiple levels. The Government agent decides the payment from the Grain for Subsidy Policy, and this decision influences the livelihood structure of households. The whole town receives the same government policy. The individual agents decide their own occupation states, and this decision influences households’ livelihood strategies and structures (for detail, see Section “Descriptions of Submodels” (1)). The household agents decide their farmland use behaviors (for detail, see Section “Descriptions of Submodels” (4)), and this decision directly changes their farmland use states. These decision-makings are modeled on each farmland grid cell.

2.2.2. What is the Basic Rationality behind Agent Decision-Making in the Model? Do Agents Pursue an Explicit Objective or Have other Success Criteria?

Among these 4 types of agents, the household agent is the basic unit of the model, and the individual agent who comprises the household agent is the smallest unit of the model. If any individual agent changes its behavior, the household agent's attributes and behaviors will change simultaneously. Using the key attributes of the households, rural households can be divided into different groups. Different groups of households have different farmland use behaviors, while households that belong to the same group have the same behaviors. Non-farming group of households prefer to rent out farmland, while pure-farming and part-farming groups of households prefer to hire farmland.

2.2.3. How do Agents Make Their Decisions?

As individual agents grow older, their occupation states change correspondingly. According to study target, we divided households into different groups (for more detail, see Section "Descriptions of Submodels" (2)). The changing occupation states of all the family members drive the change of household types. Based on questionnaires interview, we analyzed the farmland use behaviors of different types of households.

2.2.4. Do the Agents Adapt Their Behaviour to Changing Endogenous and Exogenous State Variables? And if Yes, How?

The agents adapted their behavior to changing endogenous and exogenous state variable. All of the changes of government Grain for Subsidy Policy, economic development, family occupations structure, and family livelihood structure can influence the type of households, and households' farmland use behaviors will be changed correspondingly. About the detail, see Section "Descriptions of Submodels" (2).

2.2.5. Do Social Norms or Cultural Values Play a Role in the Decision-Making Process?

No.

2.2.6. Do Spatial Aspects Play a Role in The Decision Process?

Spatial aspect plays a role in the decision process. Through local interviews we found that households evaluate farmland quality according to NPP, relief amplitude, road accessibility and slope. In our study, spatial heterogeneities can be presented by these 4 natural factors. We use the I_{total} index to express the combined impacts of these 4 factors (for more detail, see Section "Descriptions of Submodels" (3)). When households choose to plant at reduced scales, they will rent out or abandon farmland plots with inferior qualities; when households choose to plant at expanded scales, they will hire farmland plots with superior qualities.

2.2.7. Do Temporal Aspects Play a Role in the Decision Process?

Time aspect also plays a role in the decision process. As individual agents grow older, they will change their occupation states, and their family livelihood structures will be changed correspondingly. The types of households and their farmland use behavior will be changed simultaneously.

2.2.8. To Which Extent and How is Uncertainty Included in the Agents' Decision Rules?

The model includes uncertainty. Our questionnaires cover 161 households and 714 family members. However, in the whole Qianjingou town, there are 7952 households and 17500 populations. We use Monte Carlo method to simulate households in the whole town based on sampled survey data.

2.3. Learning

2.3.1. Is Individual Learning Included in The Decision Process? How Do Individuals Change Their Decision Rules over Time as Consequence of Their Experience?

Individual learning is included in the decision process. Through questionnaire analysis, we got the changing mechanism of the occupation state of individual agents (for more detail, see Section "Descriptions of Submodels" (1)). Every individual obeyed this mechanism. During the model running period, when individuals got to a certain age node, their occupation state will change to another state according to a specific probability.

2.3.2. Is Collective Learning Implemented in the Model?

Collective learning is implemented in the model. Based on empirical statistics analysis, we got the farmland use behavior rules of households in different groups (for more detail, see Section "Descriptions of Submodels" (2)). Households in different groups will learn these rules during the simulating process. After determining the types of households, their farmland use behavior will be determined according to the preset rules.

2.4. Individual Sensing

2.4.1. What Endogenous and Exogenous State Variables are Individuals Assumed to Sense and Consider in Their Decisions? Is The Sensing Process Erroneous?

Individuals are assumed to sense and consider their own ages, occupations and economic development. Households are assumed to sense their livelihood structure, economic development, government policies and farmland use states. These sensing processes are correct.

2.4.2. What State Variables of Which other Individuals Can an Individual Perceive? Is the Sensing Process Erroneous?

An individual can not perceive state variables of other individuals. Because of lack of data, we did not consider the learning between individuals in our study.

2.4.3. What is the Spatial Scale of Sensing?

The spatial scale of sensing is the grid cell. At this scale the plots state can be sensed. Through perceptions of the household agent, we got the weight values of 4 natural factors, and synthesized these natural factors into 1 index (I_{total} value).

2.4.4. Are the Mechanisms by Which Agents Obtain Information Modelled Explicitly, or Are Individuals Simply Assumed to Know These Variables?

All other variables are just known by the agents.

2.4.5. Are the Costs for Cognition and the Costs for Gathering Information Explicitly Included in the Model?

The costs for cognition and the costs for gathering information are not included in the model.

2.5. Individual Prediction

2.5.1. Which Data do the Agents Use to Predict Future Conditions?

Based on the household structures (family size, age, occupation and livelihood) and the changing mechanisms of the occupation states of individual agents in the last year, we can determine which groups the households belong to in the next year. Based on the groups they belong to, we can determine households' farmland use behavior in the next year. Based on the I_{total} values of plots planted by each household, we can determine how many plots and which plots will be rented out/hired/abandoned.

2.5.2. What Internal Models are Agents Assumed to Use to Estimate Future Conditions or Consequences of Their Decisions?

Agents use "farmland aggregation degree" (*FAD*) index (see Section 4.2.1 for more detail) to estimate future conditions or consequences of their decisions.

2.5.3. Might Agents Be Erroneous in the Prediction Process, and How Is It Implemented?

We use probability method and households types to predict households' behavior. This brings stochastics to some extent, but households' behavior is definite from a global perspective.

2.6. Interaction

2.6.1. Are Interactions among Agents and Entities Assumed as Direct or Indirect?

The interactions between households and plots are direct. The interactions between individuals and plots are indirect, and individuals have to interact with plots with the help of the household they belong to.

2.6.2. On What do the Interactions Depend?

The interactions between households and plots depend on the livelihood strategies of households, and the whole economic benefit of plots. To simplify simulation, we divided the households into 5 groups based on the household economic sources and the household livelihood demand for farmland and non-agricultural labor forces (for more detail, see Section "Descriptions of Submodels" (2)). Different groups of households have different interactions with plots.

2.6.3. If the Interactions Involve Communication, How Are Such Communications Represented?

These interactions do not involve communication.

2.6.4. If a Coordination Network Exists, How does It Affect the Agent Behaviour? Is the Structure of the Network Imposed or Emergent?

No coordination network exists in our simulation.

2.7. Collectives

2.7.1. Do the Individuals form or Belong to Aggregations that Affect and Are Affected by the Individuals? Are These Aggregations Imposed by the Modeller or do They Emerge during the Simulation?

The household agent is the basic unit of the model, and the individual agent who comprises the household agent is the smallest unit of the model. Some individuals comprise a household based on certain kinship and social relationships. Using the key attributes of the households, rural households can be divided into different groups. Households that belong to the same group have the same farmland use behaviors. The household emerges during the simulation, while the household groups are imposed by the modeler.

2.7.2. How are Collectives Represented?

We first divided households into 5 groups (for more detail, see Section "Descriptions of Submodels" (2)), and determine the number, ages and occupation structures of the family members of each types of households. Because of NPP heterogeneities, we evenly distributed the plots with high or low NPP to each household. By counting family members in each household, this model allocates the same number of plots to each household. The plots that planted by the same household are distributed adjacently. The households in the same group do not have obvious spatial aggregation phenomenon.

2.8. Heterogeneity

2.8.1. Are the Agents Heterogeneous? If Yes, Which State Variables and/or Processes Differ between the Agents?

The individual agents and household agents are heterogeneous. The occupation states are different from individual agents, and the farmland use decisions agents are different between household agents.

2.8.2. Are the Agents Heterogeneous in Their Decision-Making? If Yes, Which Decision Models or Decision Objects Differ between the Agents?

The individual agents and household agents are heterogeneous in their decision-making. The occupation states of individual agents are different (for more detail, see Section "Descriptions of Submodels" (1)), and the farmland use behaviors of households in different groups are heterogeneous during their decision-making process (for more detail, see Section "Descriptions of Submodels" (4)).

2.9. Stochasticity

What Processes (Including Initialisation) Are Modelled by Assuming They are Random or Partly Random?

At the initialization of the model, because of lack of cadastral data, we randomly distributed households' spatial location. We allocated adjacent plots randomly to each household.

2.10. Observation

2.10.1. What Data Are Collected from the ABM for Testing, Understanding and Analyzing It, and How and When Are They Collected?

Farmland use states (abandoned plots, rented plots, or plots planted by owners), the number of households in different *FAD* intervals (zero *FAD*, low *FAD*, middle *FAD*, high *FAD* and super high *FAD*), and the number of different groups of households are collected from the ABM. These data were collected at the end of each year.

2.10.2. What Key Results, Outputs or Characteristics of the Model Are Emerging from the Individuals? (Emergence)

We counted the number of 5 types of households in the whole town in the next 30 years. We want to observe that, what the trend of non-farm employment is in the next 30 years. We counted the number of plots with different farmland use states. We want to observe that, what the trend of the number of rented plots and abandoned plots is in the next 30 years, and whether the sustainability of farmland system is endangered or not in the future. We counted the number of households in 5 aggregation intervals, and we want to know what the trend of farmland management rights redistribution is in the next 30 years.

3. Details

3.1. Implementation Details

3.1.1. How Has the Model Been Implemented?

Using Java and the RepastJ toolbox [43], we constructed a multi-agent model of regional farmland use change in the Eclipse integrated development environment.

3.1.2. Is the Model Accessible, and if so Where?

The model is accessible. If readers want to see the source code of this model, you can send email to us.

3.2. Initialisation

3.2.1. What is the Initial State of the Model World, *i.e.* at Time t = 0 of a Simulation Run?

To improve the simulating efficiency and facilitate the simulation of the ownerships between individuals and farmland, we set the area of 1 farmland plot (one plot corresponds to one farmland grid cell) is 0.9 hectare, which equals to the area of farmland allocated to each person. Therefore, 1 person was allocated the area of 1 farmland plot (1 individual corresponds to 1 plot). To maintain consistency with the statistical data, we resized the land use raster cell size from 100 m × 100 m to 96 m × 96 m.

Model initializations include spatial environment initialization and input parameter initialization. A total of 17,056 plots and 17,056 individual agents were added into this model. The input spatial environmental layers include land use data, NPP, slope and road accessibility. Because of NPP heterogeneities, we needed to evenly distribute the plots with high or low NPP to each household. How to relate an individual agent's state variables and a household group agent's variables, and impute the individual agent and the household group agent into model space were the key steps of the initialization. The household types determine the number, ages and occupation structures of the family members.

At the initialization of the model, one family member corresponded to one plot (this relationship changed at a later stage because of farmland rent and abandonment). By counting family members in each household, this model allocates the same number of plots to each household, allowing the household livelihood strategies and their farmland use behaviors to be reflected in the corresponding plots.

The households in different groups have different ages and labor structures, but there are no differences in the education states. We initialized the population, age and occupation structures of 5 types of households. In this model, men and women cannot marry until men are older than 22 and women are older than 20. The age difference between parents and children must be greater than 20 years, and the age difference between married couples must be within 5 years. The main initialization steps included:

(1) Initializing the population, age and occupation structures of 5 types of households (Because of complexity, we listed the tables of these structures as Supplementary Materials 3). Subsidy-dependent households lack young and middle-aged laborers, and non-farming, pure-farming and part-farming households must have young and middle-aged laborers;

(2) Calculating the farmland areas of each person using the statistical yearbook data. Using remote sensing data, we obtained the spatial location of the farmland and resized the grid resolution so that one farmland grid represented one person's farmland area;
(3) Through questionnaire analysis, we obtained the percents of the 5 types of households in the sampled data, and using the Monte Carlo method, we obtained the proportion of the 5 types of households in the overall data;
(4) We calculated the total farmland area of each household by multiplying the number of family members by the farmland areas of each person. Then, we allocated this number to each household.

3.2.2. Is the Initialisation Always the Same, or Is It Allowed to Vary among Simulations?

The initialization is not always the same. Through questionnaires analysis, we got the percents of the 5 types of households in the sampled data. We used Monte Carlo method to get the proportion of the 5 types of households in the overall data. This method brings the randomness, and makes every initialization a little different.

3.2.3. Are the Initial Values Chosen Arbitrarily or Based on Data?

In our model, the initial values are chosen based on on-the-spot questionnaires survey, remote sensing data and census data.

3.3. Input Data

Does the Model Use Input from External Sources such as Data Files or other Models to Represent Processes that Change over Time?

The model does not use input data to represent time-varying processes.

3.4. Submodels

3.4.1. What, in Detail, Are the Submodels that Represent the Processes Listed in 'Process Overview and Scheduling'?

The submodels represented the processes listed in "Process overview and scheduling" include individual state transfer submodel, households classification submodel, spatial environment distribution submodel, and households' farmland use decisions submodel. For detailed information of each submodel, see Section 4.3.4.

3.4.2. What are the model parameters, their dimensions and reference values?

We listed the main parameters in Table S1. From Table S1, we can see the meaning, initial values, data sources and changing rules of these parameters. We listed the common variables in front of Table S7, while the parameters of each submodel are listed separately below the corresponding submodels.

Table S1. The main parameters and their default values of the model.

Parameters	Meaning	Initial Values	Data Sources	Changing Rules
averageLand	Farmland areas per person	0.9 hectare	Statistical yearbook	Fixed
maxDeathAge	Longevity	65–100	Questionnaires	Randomly changed
numAgents	Total population	17,500	Statistical data	Changed at the next time slice
FAD	The *FAD* of farmland plots for each household	1	Questionnaires	Changed at the next time slice
nppClass	Npp classes (gc/(m^2*a))	Class 1: 584–761 Class 2:407–584 Class 3: 230–407 Class 4: 54–230	Remote sensing data and questionnaires	Fixed
		Individual agents state transfer submodel		
ageNode	The age nodes that individuals change their occupation states	18, 22, 47, 55, 60, 65	Questionnaires	Fixed
probability	The probability individuals change their occupation from one state to another.	0–100%	Questionnaires	Fixed
		Household classification submodel		
percentage	The percentage of non-farming, pure-outworking, part-farming, pure-farming, subsidy-dependent groups	0.41, 0.11, 0.25, 0.15, 0.08	Questionnaires	Changed at the next time slice
everEarned	Work income per person	10,000 yuan/a	Questionnaires	Fixed
subsidyGrain	Payment of Grain Subsidy Policy	430.7 yuan/hectare	Questionnaires	Fixed
cropPrice	Price of naked oats	2.49 yuan/kg	Questionnaires	Fixed
landYield	Yield of farmland	NPP1: 1500 kg/hectare NPP2: 1125 kg/hectare NPP3: 750 kg/hectare NPP4: 375 kg/hectare	Remote sensing data and questionnaires	Fixed
rentPrice	Prices of land rent	NPP1: 600 yuan/hectare NPP2: 525 yuan/hectare NPP3: 450 yuan/hectare NPP4: 375 yuan/hectare	Remote sensing data and questionnaires	Fixed
		Spatial environment allocation submodel		
cellSize	The spatial resolution of each grid cell	96 m × 96 m	Remote sensing data, questionnaires and statistical data	Fixed
weight	The weights of 4 factors, which are used to combine the 4 factors	W_{npp} = 0.4, W_{road} = 0.2, W_{slope} = 0.2, W_{relief} = 0.2	Questionnaires	Fixed
I_{total}	The combined index of 4 natural factors	Range from 0 to 1. Need calculation.	Remote sensing data and questionnaires	Fixed
		Households' farmland use submodel		
k	The maximum plots that each agricultural laborer can plant	10	Questionnaires	Fixed
numofTransferPlots	The number of plots each household wanted to transfer	Need further calculation.	Questionnaires and need further analysis	Changed at the next time slice

3.4.3. How Were the Submodels Designed or Chosen, and How Were They Parameterised and then Tested?

We will introduce 4 submodels in detail. The design and parameterized processes are displayed as follows.

(1) Individual State Transfer Submodel

The detailed descriptions of the changing mechanisms of the states of individual agents (Figure S2) are as follows:

(1) The age of the juvenile and adult node is 18 years old. When the age of an individual agent is equal to or greater than 18 years, 10% will become undergraduates (S1→S2), 30% will become farmers (S1→S3), and 60% will become migrant workers;
(2) The age of the undergraduate education and working node is 22 years old. When the age of an individual agent is equal to or greater than 22 years, 100% will become stable workers (S2→S7);
(3) An important age node is 47 years. When 18 ≤ age ≤ 47 or 47 ≤ age ≤ 55, migrant workers and farmers will exchange with each other at a certain probability level. When 18 ≤ age ≤ 47, 55% farmers will become migrant workers (S3→S4), and 25% migrant workers will become farmers (S4→S3). When 47 ≤ age ≤ 55, 45% migrant workers will become farmers (S5→S6);
(4) The age of the migrant workers stopping work outside and becoming farmers node is 55 years. When the age of an individual agent is equal to or greater than 55 years old, 100% will become farmers (S8→S6);
(5) The age of the farmers retiring node is 65 years. When the age of an individual agent is equal to or greater than 65, farmers will stop farming activities (S6→S9);
(6) The age of the stable workers retiring node is 60 years. When the age of an individual agent reaches 60, stable workers will retire (S7→S9).

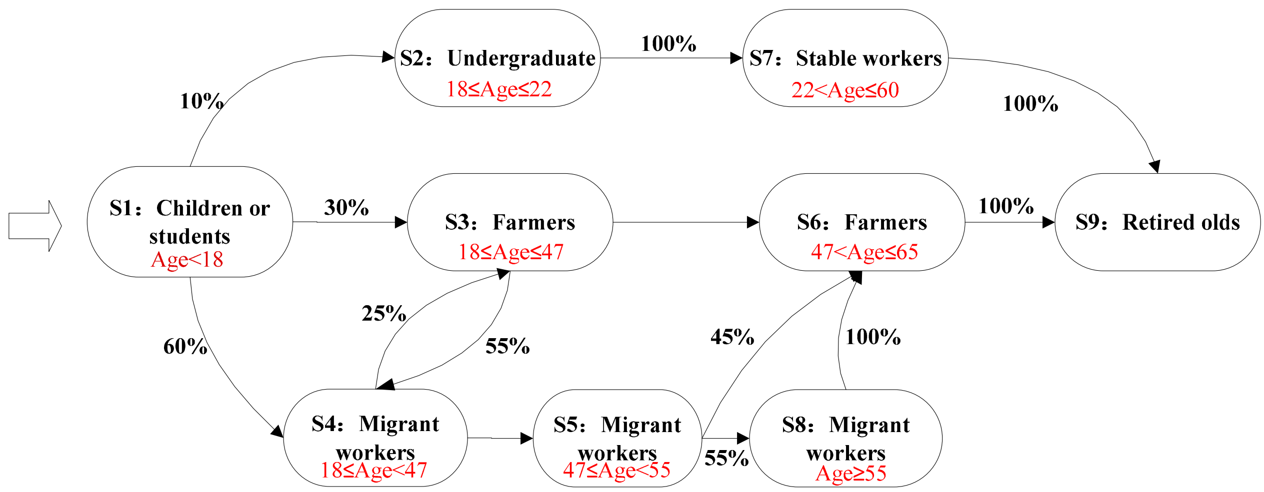

Figure S2. The changing mechanisms of the occupation state of individual agents (modified from [45–47]). Note: Six important age nodes are 18, 22, 47, 55, 60 and 65. Percentages represent the probabilities of individual agents changing their occupation state. S represents the occupation state.

(2) Households Classification Submodel

The total income of the household agent is the sum of the income of all family members. The household economic sources include operating income (crop income and income from raising animals), income from wages (migrant work income), transferred income (social insurance, minimum living standard and the payments from the Grain for Subsidy Policy) and property income (income from renting land). According to the research object and the main components of the household economy, this model only takes crop income, migrant work income, renting land income and the payments from the Grain for Subsidy Policy into account. The household income was calculated as

$$I = \sum_{i=1}^{m} O_i + \sum_{j=1}^{n} A_j + \sum_{k=1}^{p} R_k + \sum_{l=1}^{q} G_l \tag{S2}$$

where I represents the total income of the household; Oi represents the migrant work income of the i_{th} individual who travels for a job; m is the number of migrant workers; A_j is the crop income of the j_{th} farmland plot, and n is the number of agricultural labor forces; R_k is the rental income of the k_{th} farmland plot, and p is the number of the rented land plots; G_l is the payment of the l_{th} farmland plot, and q is the total amount of farmland plots owned by the household.

According to the household economic sources and the household livelihood demand for farmland and non-agricultural labor forces, we divided the households into 5 groups: subsidy-dependent, pure-farming, part-farming, non-farming and pure-outworking groups (Figure S3). Households in the pure-farming group rely on farmland and agricultural labor, and crop income is their entire income; households in subsidy-dependent group rely on government subsidies and they do not have agricultural or non-agricultural incomes; households in the pure-outworking group do not have agricultural labor, and all labor forces travel to their jobs; households in the part-farming group have both non-agricultural and agricultural labor, and farming income is their main income; and households in the non-farming group have both non-agricultural and agricultural labor, and non-farm income is their main income.

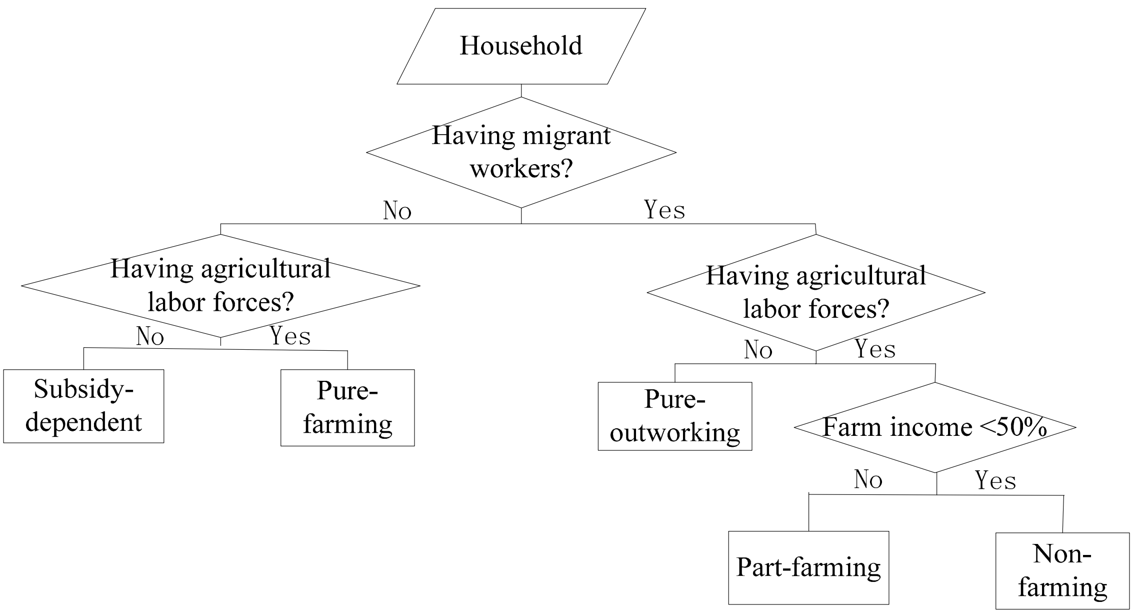

Figure S3. The decision-making tree of the household group classification.

(3) Spatial Environment Synthesization Submodel

Households evaluate farmland quality according to NPP, relief amplitude, road accessibility and slope. To describe farmland quality, we need combine these factors into 1 index [45, 47]. We use the I_{total} index to express the combined impacts of these 4 factors. The greater the I_{total} value is, the better the farmland quality is; the calculation formula is

$$I_{\mathrm{total}} = I_{\mathrm{npp}} \times W_{\mathrm{npp}} + I_{\mathrm{road}} \times W_{\mathrm{road}} + I_{\mathrm{slope}} \times W_{\mathrm{slope}} + I_{\mathrm{ra}} \times W_{\mathrm{ra}} \quad \text{(S3)}$$

$$W_{\mathrm{npp}} + W_{\mathrm{road}} + W_{\mathrm{slope}} + W_{\mathrm{ra}} = 1 \quad \text{(S4)}$$

In formula (S3), I_{npp}, I_{road}, I_{slope} and I_{ra} refer to the influences of NPP, road accessibility, slope and relief amplitude, respectively. W_{npp}, W_{road}, W_{slope} and W_{ra} refer to the weights of NPP, road accessibility, slope and relief amplitude, respectively. The sum of these four weights is 1 (formula (S4)). I_{total} is a function with values between 0 and 1; therefore, we needed to normalize these 4 impact factors to 1 (formulas (S5)–(S8)).

$$I_{\mathrm{npp}} = NPP/NPP_{\mathrm{max}} \quad \text{(S5)}$$

In formula (S5), NPP_{max} refers to the maximum NPP. We divided the NPP value by NPP_{max} for normalization purposes. Obviously, the greater the *NPP* value is, the greater the I_{npp} value is.

$$I_{\mathrm{road}} = 1 - Road\_Dist/Road\_Dist_{\mathrm{max}} \quad \text{(S6)}$$

In formula (S6), $Road\_Dist$ refers to the distance to the road network, and $Road\_Dist_{\mathrm{max}}$ refers to the maximum distance to the road network. Here, we divided the $Road\_Dist$ value by $Road\_Dist_{\mathrm{max}}$ for normalization purposes. Obviously, the greater the $Road\_Dist$ value is, the smaller the I_{road} is.

$$I_{\mathrm{slope}} = \begin{Bmatrix} 1, slope \leq 5 \\ -0.1 \times slope + 1.5, 5 < slope \leq 15 \\ 0, 15 < slope \leq 20 \end{Bmatrix} \quad \text{(S7)}$$

Formula (S7) is the normalized segmented function of the slope. Based on China's forest law enforcement regulations, the slope is divided into 3 classes. If the slope is greater than 20°, the farmland is not suitable for planting. Between 5° and 15°, the impact decreases linearly from one to zero. Obviously, the greater the slope value is, the smaller the I_{slope} value is.

$$I_{\mathrm{ra}} = \begin{Bmatrix} 1, ra \leq 30 \\ -ra/75 + 1.4, 30 < ra \leq 75 \\ 0.4, 75 < ra \leq 127 \end{Bmatrix} \quad \text{(S8)}$$

Formula (S8) is the normalized segmented function of relief amplitude, and ra refers to relief amplitude. If the *ra* is smaller than 30, the geomorphic type of the farmland is a plain, and the I_{ra} is equal to one; if the *ra* is between 30 and 75, the geomorphic type is a hill, and the I_{ra} decreases linearly from one to 0.4; if the *ra* is greater than 75, the geomorphic type is a highland, and the I_{ra} is equal to 0.4 [50].

(4) Households' Farmland Use Decisions Submodel

Farmland use decision behaviors of the household groups include renting out, renting in, and abandonment of farmland. The households within a group have the same farmland use behaviors. The percent of each type of household and of each type of household that transferred their farmland are shown in Figure S4. The households in the non-farming group constituted the largest part of the total households (41%). The number of households in this group who reduced the scale of their farmland was the highest (52%), and the percent of households who rented in farmland was 44%. The households in the part-farming group comprised the second largest part of the total households (25%). The percent of households who rented in farmland was 54%, and the percent of households who reduced the scale of their farmland was 28%. The number of households in pure-farming group was the third largest (15%), and the percent of households who rented in farmland was 72%. Because of farmland dependencies, the households in this group did not reduce the scale of their farmland. The number of households in the pure-outworking group was the fourth largest (11%). Because of a lack of agricultural labor forces, the households in this group did not plant farmland, and they rented out or abandoned all of their farmland. The number of households in the subsidy-dependent group was the lowest (8%). Because of a lack of labor forces, the households in this group rented out or abandoned all of their farmland.

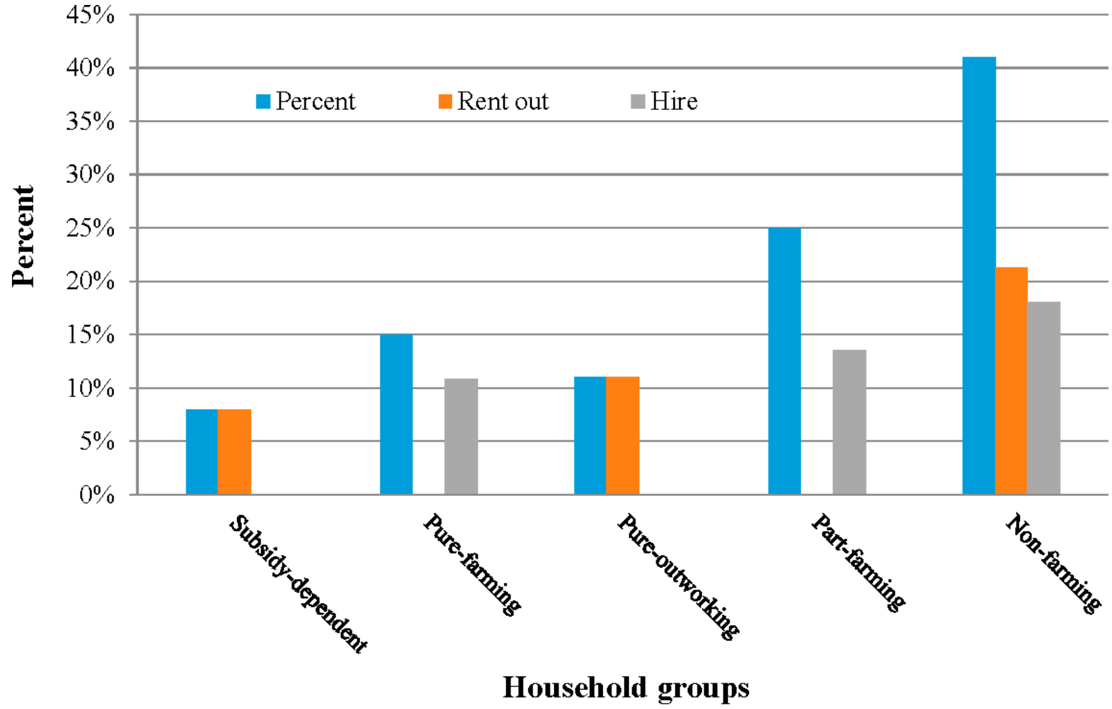

Figure S4. The percent of each type of household and the percent of each type of household that rented in/hired their farmland.

Supplementary Materials 2

The state variables and parameters of entities will be listed in Tables S2–S7 as follows. In order to simplify these descriptions, we only listed the main state variables here.

Table S2. The state variables of Landscape Cells.

State Variables	Brief Description	State Variables	Brief Description
coordinates	X and Y coordinate of the Cell	roadAccessibility	The distance to the main road network.
landUseType	6 land use types are included, *i.e.*, farmland, forestland, grassland, water bodies, building land and unused land.	slope	The slope value of study area.
NPP	Net primary productivity of farmland. We use this index to refer to productivity of farmland.	reliefAmplitude	The relief amplitude of study area.

The farmland cell is part of landscape cell. Because of its importance in our study, we list its state variables separately.

Table S3. The state variables of Farmland Cells.

State Variables	Brief Description	State Variables	Brief Description
classFarmland	We divided farmland into 4 classes according to its NPP values in equal interval. Class 1 corresponds to NPP values from 584 to 761 gc/($m^2 \times$ a), class 2 corresponds to NPP values from 407 to 584 gc/($m^2 \times$ a), class 3 corresponds to NPP values from 230–407 gc/($m^2 \times$ a), class 4 corresponds to NPP values from 54 to 230 gc/($m^2 \times$ a).	yieldFarmland	The yield of farmland. Different classes of farmland have different yield. Class 1: 1500 kg/ha, class 2: 1125 kg/ha, class 3: 750 kg/ha, class 4: 375 kg/ha.
rentalFarmland	The land rent of farmland. Different classes of farmland have different land rent. Class 1: 600 yuan/ha, class 2: 525 yuan/ha, class 3: 450 yuan/ha, class 4: 375 yuan/ha	cellSize	96 m × 96 m
I_{total}	The combined impacts of the natural factors. See Section 4.3.4 in detail.		

Table S4 The state variables of individual agent.

State Variables	Brief Description	State Variables	Brief Description
coordinates	X and Y coordinates of the individual	farmingIncome	The farming income of individuals.
age	The age of individuals, ranging from 1 to 100.	maxAge	The longevity of individuals. (65–100 years old)
gender	The gender of individuals. (0: male, 1: female)	workIncome	The migrant work income of individuals.
education	The education states of individuals. (0: primary school or below, 1: junior middle school, 2: senior middle school, 3: technical secondary school, 4: university or above).	occupationState	The occupation states of individuals. (S1: children or student, S2: undergraduate, S3: farmer, S4: migrant worker, S5: stable worker, S6: retired)

Table S5. The state variables of household agent.

State Variables	Brief Description	State Variables	Brief Description
amountofLand	The number of plots that each household plants.	selfFarmNumber	The number of plots planted by the owner
amountofFamilyM	The number of family members each household has.	rentFarmNumber	The number of plots hired/rented by the household
individualAgent array	The array of family members.	noFarmNumber	The number of plots abandoned by the household
familyLand array	The array of farmland plots planted by each household.	farmerNumber	The number of farmers in the household
parent	Boolean variable. whether the parent who want to give birth to a child exists in the household.	outworkNumber	The number of individuals who travels for a job
rentState	Boolean variable. Whether each plot is rented or not.	oldersNumber	The number of the olders
hireLandNumber	The number of plots hired by each household	aggregationIndice	The aggregation degree of plots planted by the household. About its definition see Section 4.2.1.
rentGained	The total income of hired plots	averageLand	The area of farmland per capita

Table S6. The state variables of household group agent.

State Variables	Brief Description
groupType	The types of the household group: subsidy-dependent, pure-farming, part-farming, non-farming and pure-outworking groups
k	The maximum planting ability of each agricultural labor force

The government's Grain Subsidy Policy has had an effect on household livelihoods and their farmland use modes. The households in this study area received the same governmental policies. Therefore, there is only one government agent in this model, and there are no x or y coordinate information.

Table S7. The state variables of government agent.

State Variables	Brief Description
subsidyGSP	The subsidy of the Grain for Subsidy Policy per hectare
isGrain	Whether government carries out the Grain for Subsidy Policy or not

Supplementary Materials 3

Tables S8–S18 list the population, age and occupation structures of 5 types of households.

Table S8. Percentages of family size of subsidy-dependent households.

Family Size	2	3	4
Percentage	40%	30%	30%

Table S9. Percentages of family size of non-farm and pure-farm households.

Family Size	**2**	**3**	**4**	**5**	**6**	**7**
Percentage	5%	10%	25%	20%	25%	15%

Table S10. Percentages of family size of part-farm households.

Family Size	**4**	**5**	**6**	**7**
Percentage	25%	20%	25%	15%

Table S11. Percentages of family size of pure-outwork households.

Family Size	**2**	**4**	**5**	**6**	**7**
Percentage	5%	15%	28%	25%	27%

Table S12. Percentages of ages of subsidy-dependent households.

Age Stage	**0–10**	**11–18**	**65**
Percentage	30%	30%	40%

Note: Subsidy-dependent households are lack of the young and middle-aged labors, and non-farm, pure-farm and part-farm households must have the young and middle-aged labors.

Table S13. Percentages of ages of the other 4 types of households.

Age Stage	**0–10**	**11–20**	**21–30**	**31–40**	**41–50**	**51–60**	**61–70**	**>70**
Percentage	6%	16%	21%	17%	22%	9%	5%	4%

Table S14. Family members, ages and occupations of subsidy-dependent households.

Family Members	**Subsidy-Dependent Households**
2	1/3: one person older than 65, one juvenile younger than 18.
	2/3: two elderly couple older than 65.
3	1/2: one elderly person older than 65, two juveniles younger than 18.
	1/2: two elderly couple older than 65, one juvenile younger than 18.
4	Two elderly couple older than 65, two juveniles younger than 18.

Note: lack of the young and middle-aged laborers. Old persons are retired olds, and juveniles are students or children.

Table S15. Family members, ages and occupations of pure-farm households.

Family Members	Pure-Farm Households
2	1/3: one parent with age from 20 to 65, occupation is farmer; one child (if age is greater than 18, his or her job is a farmer, else is a student).
	2/3: two parents with age from 20 to 25, both of their occupations are farmers.
3	1/2: two parents with age from 20–65, both of their occupation are farmers; one child (if age is greater than 18, his or her job is a farmer, else is a student).
	1/2: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parent.
4	1/3: two parents with age from 20–65, both of their occupations are farmers; two children are 20 years younger than the parents. If their ages are greater than 18, their jobs are farmers, else are students.
	2/3: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents, and their jobs are farmers; one child is 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
5	1/3: two parents with age from 20–65, both of their occupations are farmers; three children are 20 years younger than the parents (if the child's age is greater than 18, his or her job is a farmer, else is a student).
	1/3: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents, and their jobs are farmers; one child is 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/3: two parents with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents, and their jobs are farmers; one child is 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
6	2/5: two parents with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents, and their jobs are farmers; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	2/5: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents, and their jobs are farmers; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/5: two parents with age from 20–65, both of their occupations are farmers; four children are 20 years younger than the parents. If their ages are greater than 18, their jobs are farmers, else are students.
7	1/2: two parents with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents, and their jobs are farmers; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/2: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents, and their jobs are farmers; four children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).

Note: the age difference of married couples is within 5, and the age difference of parents and children is 20 years.

Table S16. Family members, ages and occupations of part-farm households.

Family Members	Part-Farm Households
4	1/2: two parents with age from 20–65, female is a farmer while male is a migrant worker; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/4: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents. Female is a farmer while male is a migrant worker; one child is 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/4: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents. Female is a farmer while male is a migrant worker.
5	1/4: two parents with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents. Female is a farmer while male is a migrant worker; one child is 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/2: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parent. Female is a farmer while male is a migrant worker; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/4: two parents with age from 20–65, and female is a farmer while male is a migrant worker; three children are 20 years younger than the parents (if age is greater than 18, his or her job is a farmer, else is a student).
6	2/5: two parents with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents. Female is a farmer or a migrant worker while male is a migrant worker; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	2/5: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parent. Female is a farmer or a migrant worker while male is a migrant worker; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/5: two parents with age from 20–65, female is a farmer or a migrant worker while male is a migrant worker; four children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
7	1/2: two parents with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parents. Female is a farmer or a migrant worker while male is a migrant worker; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).
	1/2: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parent. Female is a farmer or a migrant worker while male is a migrant worker; four children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer, else is a student).

Note: the age difference of married couples is within 5, and the age difference of parents and children is 20 years.

Table S17. Family members, ages and occupations of non-farm households.

Family Members	Non-Farm Households
2	1/2: one couple with age from 20–65, female is a farmer while male is a migrant worker.
	1/2: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one male child with age greater than 18, and he is a migrant worker.
3	1/2: one couple with age from 20–65, female is a farmer while male is a migrant worker; one child is 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
	1/2: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer); one couple are 20 years younger than the parent. Female is a farmer while male is a migrant worker.
4	1/4: one couple with age from 45 to 65, female is a farmer while male is a migrant worker; one male child is older than 18, and he is a migrant worker; one child with age younger than 18, he or she is a student.
	1/4: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a farmer or a migrant worker); one couple are 20 years younger than the parent, and female is a farmer while male is a migrant worker; one male child is older than 18, and he is a migrant worker.
	1/2: two parents with age from 45 to 65, female is a farmer while male is a migrant worker; one couple are 20 years younger than the parents. Female is a farmer while male is a migrant worker.
5	1/4: one couple with age from 45 to 65, female is a farmer while male is a migrant worker; one male child is older than 18, and he is a migrant worker; two children with age from 0 to 25 (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
	1/2: two parents with age from 45 to 65, female is a farmer while male is a migrant worker; one couple are 20 years younger than the parent, and female is a farmer while male is a migrant worker; one male child is 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
	1/4: one male parent with age from 45 to 65, he is a migrant worker; one couple are 20 years younger than the parents. Female is a farmer while male is a migrant worker; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
6	1/2: two parents with age from 45 to 65, female is a farmer while male is a migrant worker; one couple are 20 years younger than the parent, and female is a farmer while male is a migrant worker; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
	1/4: one male parent with age from 45 to 65, he is a migrant worker; one couple are 20 years younger than the parents. Female is a farmer while male is a migrant worker; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
	1/4: one couple with age from 45 to 65, female is a farmer while male is a migrant worker; one male child is older than 18, and he is a migrant worker; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
7	1/2: two parents with age from 45 to 65, female is a farmer while male is a migrant worker; one couple are 20 years younger than the parent, and female is a farmer while male is a migrant worker; one male child is older than 18, and he is a migrant worker; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).
	1/2: one male parent with age from 45 to 65, he is a migrant worker; one couple are 20 years younger than the parent, and female is a farmer while male is a migrant worker; one male child is older than 18, and he is a migrant worker; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a farmer or a migrant worker, else is a student).

Table S18. Family members, ages and occupations of pure-outwork households.

Family Members	Pure-Outwork Households
2	2/3: one couple with age from 25 to 45, they are migrant workers.
	1/3: one parent with age greater than 45 (if age is greater than 65, his or her is a retiree, else is a migrant worker); one male child is older than 18, and he is a migrant worker.
4	1/2: two parents with ages greater than 65, they are retirees; one couple are 20 years younger than the parents, and both of them are migrant workers.
	1/2: one male parent with age from 45 to 65, he is a migrant worker; one couple are 20 years younger than the parent, and both of them are migrant workers; one child with age from 0–18, he or she is a student.
5	1/3: two parents with ages greater than 65, they are retirees; one couple are 20 years younger than the parents, and both of them are migrant workers; one child with age from 0–18, he or she is a student.
	2/3: one parent with age greater than 65, he or she is retiree; one couple are 20 years younger than the parent, and both of them are migrant workers; two children are 20 years younger than the couple (if age is greater than 18, his or her job is a migrant worker, else is a student).
6	1/3: two parents with ages greater than 65, they are retirees; one couple are 20 years younger than the parents, and both of them are migrant workers; two children with ages from 0–18, they are students.
	2/3: one couple with age from 25 to 45, they are migrant workers; four children are 20 years younger than the couple (if age is greater than 18, his or her job is a migrant worker, else is a student).
7	2/3: two parents with ages greater than 65, they are retirees; one couple are 20 years younger than the parents, and both of them are migrant workers; three children are 20 years younger than the couple (if age is greater than 18, his or her job is a migrant worker, else is a student).
	1/3: one parent with age greater than 65, he or she is retiree; one couple are 20 years younger than the parent, and both of them are migrant workers; four children are 20 years younger than the couple (if age is greater than 18, his or her job is a migrant worker, else is a student).

Note: nobody is a farmer.