Modelling farmland conversion integrating multi-agent systems and resource economics theory

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1. Introduction

Farmland conversion, i.e. conversion of farmland into non-agricultural construction land, is an unavoidable trend in global economic development(Fazal 2001; Tan et al. 2005; Bugri 2008). In China, which is relatively short of farmland resources and yet in the phase of accelerating urbanization, conversion of farmland is closely related to national food security, ecological security as well as sustainable land resource use(Liu et al. 2005). Therefore, a reasonable allocation of farmland conversion quota is of great importance. Compared with traditional methods such as empirical statistics, systems dynamics and Cellular Automata, Multi-Agent Systems (MAS), integrating macroscopic phenomena and micro decision-making, is more able to interpret the driving mechanisms of LUCC from the view of interaction relations of driving agents(Manson 2006; Li and Liu 2008; Tian et al. 2011). Since MAS is advantageous in the study of LUCC, this research aims to explore such issues as feedback between agents and their environment, and corporation and competition between agents. Based on the decision-making framework of multi agent systems with full consideration of agents' heterogeneity and resource economics model, a mode for spatio-temporal allocation of farmland conversion quota is developed.

2. Model for spatio-temporal allocation of farmland conversion quota

2.1 Overview of the model

The model for spatio-temporal allocation of farmland conversion quota consists of four parts, i.e., environment, multi-agent systems, GIS and the core part–a set of decision-making rules. The environment component includes land use, soil, land price, transportation and public facilities, and the multi-agent systems component includes various agents like governments, residents, farmers and industrial enterprises. Agents may be affected by the environment and may also affect the environment and change its state.

2.2 Defining decision-making rules of multi-agents

(1) Government agents

As a kind of special agents, governments do not have spatial attribute, but they allocate farmland conversion quota through planning land uses. In the course of planning, the overall objective is for spatio-temporally optimal allocation. Equal marginal benefit for various spatial resource uses is the only principle for optimal allocation of resources. If equal marginal benefits for resource use in different regions are guaranteed, maximize-ation of the overall resource use benefit or optimal spatial allocation can be achieved (Roger et al. 2002). Therefore, this principle should also be incorporated for present government agents in their spatial allocation of farmland conversion quota; only when equal marginal benefits of farmland conversion in all sub-areas are ensured, can maximal spatial allocation benefit for regional farmland conversion be achieved, as represented in

$$MR_j = MR_{j+1} = MR_{j+2} \ldots\ldots \quad (1)$$

where, MR_j, MR_{j+1} … represent net marginal benefits of farmland conversion in the sub-area j j+1, and so on. MR for each sub-area can be represented by partial derivatives of the function of overall farmland conversion benefit with respect to the quantity of farmland conversion. Tietenberg model is adapted in this research to allocate farmland conversion quota in order to achieve optimal temporal allocation for future land use(Li and Yeh 2000).

(2) Resident agents

Residents who are either in better economic conditions or unsatisfied with present living environment will hope to relocate to new residences that are more suitable for them to live. Limited to existing precious urban land, developing new residence always occupy farmlands, therefore, it is in nature a process of farmland conversion. There are three types of residents—residents moving into city from outside, existing residents relocating new places to reside and residents newly produced from existing residents. Resident agents in this study has such behaviors as moving into the city, moving out from urban areas, relocating new places to live, reproducing new residents, with such attributes as education level (E), income (S), payout (P), property (W) (difference by subtracting payout from income), age (A) and distance between working place and residence (D) are defined.

(3) Industrial enterprise agents

With the objective of profit, an enterprise agent's behavior is driven by the pursuing more profits and broader development space. Industrial enterprise agents display a feature of assembling as they tend to move to industrial zone around urban area to improve their competitiveness. Industrial enterprises in the model have such properties as scale (Z), sales(S), consumption (P),asset (U) (difference by subtracting consumption from sales), and the behavior flow quite similar to that of resident agents but with differences in specific behavior motivation. When an industrial enterprise's asset can't maintain its operation, it has to move out from present city. As industrial enterprises' reproducing behavior is rather complex which involves such factors as society and economy, it is not taken into consideration in this paper.

(4) Farmer agents

In the process of farmland conversion, farmer agents' behavior is controversial, as they hope to be closer to urban area to live a more convenient life on one hand and on the other hand, they want to keep their farmland which they live by. They have such attributes as scale (Z), income (S), and payout (P), and they retire from the model when S is below P. Slope, slope direction, soil productivity and land price are selected as feature variables, and distance to the town center, distance to the government administration center (like municipal government or district government), distance to railway, distance to urban roads and distance to expressway are selected as location feature variables, and whether it is within the farmland preservation areas, whether it is within the urban planning area, and the permitted development density are selected as planning restriction variables, neighborhood density of farmland preservation and neighborhood density of construction land are selected as neighborhood variables, and population density of country, density of gross output value of agriculture and industry in country are selected as socio-economic statistic variables. These variables jointly influence farmers' decision-making on farmland conversion.

(5) Interactions between government agents and resident, industrial enterprise, farmer agents

In the set of potential land use cells searched by government agents, the more cells government agents allow to be converted into non-agricultural construction land, the bigger the potential is farmland cell(x, y) to be applied for or accepted as non-agricultural construction land by resident, industrial enterprise and farmer agent; and vise verse. The interaction at the micro-level reflecting each agent' expectation can be represented with formula (2):

$$ {}^{new,t}P_{x,y}^{j} = \begin{cases} {}^{t}P_{x,y}^{j}(1+f_{j,x,y}) & \Delta s > 0 \\ {}^{t}P_{x,y}^{j} & \Delta s = 0 \\ {}^{t}P_{x,y}^{j}(1-f_{j,x,y}) & \Delta s < 0 \end{cases} \tag{2} $$

where, Δs is the difference of between actual expectations and psychological expectations of other agents. At the micro-level, ${}^{t}P_{x,y}^{j}$ represents the initial potential for farmland cell(x, y) to be applied for or accepted as non-agricultural construction land by resident, industrial enterprise and farmer agents, and j is the sequence number of resident, industrial enterprise and farmer agent. The agent set of resident, industrial enterprise and farmer agents will hold different ${}^{t}P_{x,y}^{j}$ respectively. ${}^{new,t}P_{x,y}^{j}$ represents the potential for farmland cell(x, y) to be applied for or accepted as non-agricultural construction land with consideration of government agent's influence; $f_{j,x,y}$ is adjustment parameter reflecting agents' psychological expectations for applying for or accepting candidate cells as non-agricultural construction land.

(6) Transition rule for farmland conversion under the interaction of multi-agents

Conversion of farmland cell is realized under the influence of multi-agent systems. Adapting weighted summation model, the potential of farmland conversion can be shown by formula (3):

$$P = (\theta C^{g}_{x,y} + (1-\theta)C^{j}_{x,y}) \quad \forall \theta \in [0,1] \tag{3}$$

where, θ represents weight parameter, P represents the potential of farmland conversion of farmland cell (x, y) under joint influence of multi-agents; $C^{g}_{x,y}$ represents the probability of farmland conversion under the influence of government agents; $C^{j}_{x,y}$ represents probability of farmland conversion under the influence of resident, industrial enterprise, farmer agents and it can be obtained through formula (4):

$$C^{j}_{x,y} = \sum_{j=1}^{L} w_j \, {}^{new,t}P^{j}_{x,y} \tag{4}$$

Where, j represents sequence number of agent type i.e. resident agents, industrial enterprise agents and farmer agents; ${}^{new,t}P^{j}_{x,y}$ represents the potential of farmland conversion of cell(x, y) of individual agent, and its calculation varies with the type of agents; w_j represents the weight assigned to agent j. The farmland conversion quota is allocated in the simulation model according to the numerical value of P from high to low.

3. Application of the model

3.1 Study area

We select City of Changsha, the core part of Changsha-Zhuzhou-Xiangtan city cluster which is a national comprehensive reform pilot area in China to build the resource-saving and environment-friendly society, as our study area.

3.2 Validation of the model

In order to validate the simulation precision of the model, making 1993 as the base year, eight groups of resident, industrial enterprise and farmer agents are input into the model to simulate farmland conversion quota allocation in Changsha of the year 2005. The simulation precision measured using Kappa coefficient of various groups are shown in table 1.

Group	1	2	3	4	5	6	7	8
Kappa	0.653	0.631	0.604	0.577	0.634	0.528	0.584	0.505

Table 1. Comparison of the simulation precision measured using Kappa coefficient of various groups

Kappa coefficient of various groups are above 0.5 and that of the 1st group is even as high as 0.653, which shows that the model can reflect the basic characteristics of spatial evolution of farmland conversion.

3.3 Scenario simulation of spatio-temporal allocation of farmland conversion quota

We assume that simulation is carried out in the four kinds of scenarios below.

Scenario A: farmland protection intension is similar to the benchmark period of the simulation. Government keeps previous farmland conversion trend and intension, with no consideration of the principle of maximal spatio-temporal allocation efficiency when allocating farmland conversion quota.

Scenario B: on the basis of previous farmland protection policies, farmland shall be strictly protected and its protection intension should be increased by 10%; government allocates farmland conversion quota in accordance with the principle of maximal spatio-temporal allocation efficiency and sustainable development.

Scenario C: farmland shall be protected on the basis of previous farmland protection policy. Meanwhile, land demand for industrial zones which make great contributions for regional economic growth, such as National New and High Technology Zone, Environmental Protection Industry Zone, Ecological Town, Great Hexi Prior Region, should be firstly satisfied. The principle of maximal spatio-temporal allocation efficiency is not taken into government's consideration in its allocation of farmland conversion quota.

Scenario D: on the basis of previous farmland protection policy, the overall farmland protection level shall be improved with cultivated land increased by 5%, orchard land by 5% and forest land by 5%. Government allocates farmland conversion quota in accordance with the principle of maximal spatio-temporal allocation efficiency and sustainable development.

Simulations of spatio-temporal allocation of farmland conversion quota in Changsha from 2006 to 2020 are displayed in fig. 1.

After comprehensive analysis of simulation results under various scenarios, we can observe that: 1) under scenario A, present farmland conversion trend in the study area will continue until 2020; construction land shall expand along present construction land to the suburbs in large quantity; cultivated, forest, orchard land and water area will be converted into non-agricultural land continuously; and it's mainly the cultivated and forest land that will be converted into construction land. Under scenario B, as the principle of maximal spatio-temporal allocation efficiency is incorporated in government's allocation of farmland conversion quota and protection intensity for cultivated land is increased, farmland conversion has been restricted to certain degree;

loss of cultivated, forest, orchard land as well as water area is decreased accordingly, which is more obvious in northern and southern-east part of the study area. Under scenario C, as demand should be fully satisfied of the National New and High Technology Zone, Environmental Protection Industry Zone, Ecological Town, Great Hexi Prior Region in Changsha, construction land expands in large quantity around these areas; and its main source comes from cultivated, forest land. The expanded areas locate mainly in the National New and High Technology Zone and Great Hexi Prior Region in Changsha in the west and Yuhua Environmental Protection Industry Zone and Tianxin Ecological Town in the south; in the north, however, there is less farmland loss for lack of industrial zone with large demand of land. Under scenario D, because of double constraints of the principle of maximal spatio-temporal allocation efficiency and increased protection intensity for overall farmland, farmland conversion is under a stricter control, and the cultivated, forest, orchard land as well as water area are under a more efficient protection, though construction land is still expanding.

4. Conclusion and Discussion

This paper has developed a model for spatio-temporal allocation of farmland conversion quota on the basis of the principal of maximal spatio-temporal allocation efficiency and sustainable development. Through integrating multi-agent system and resource economics model, we have in this model defined decision-making rules of multi-agents, established comprehensive decision-making rules, and obtained spatial and temporal explicit representation of various agents' decision-making behaviors in the process of farmland conversion. The model is applied to scenario simulation of allocation of farmland conversion quota in Changsha. Although we have designed four kinds of agents' decision-making rules in farmland conversion, there is a larger system of agents which motivate farmland conversion and a series of more complicated decision-making rules in reality; therefore, further effort should be made to improve multi-agent system and gain an exact representation of decision-making rules.

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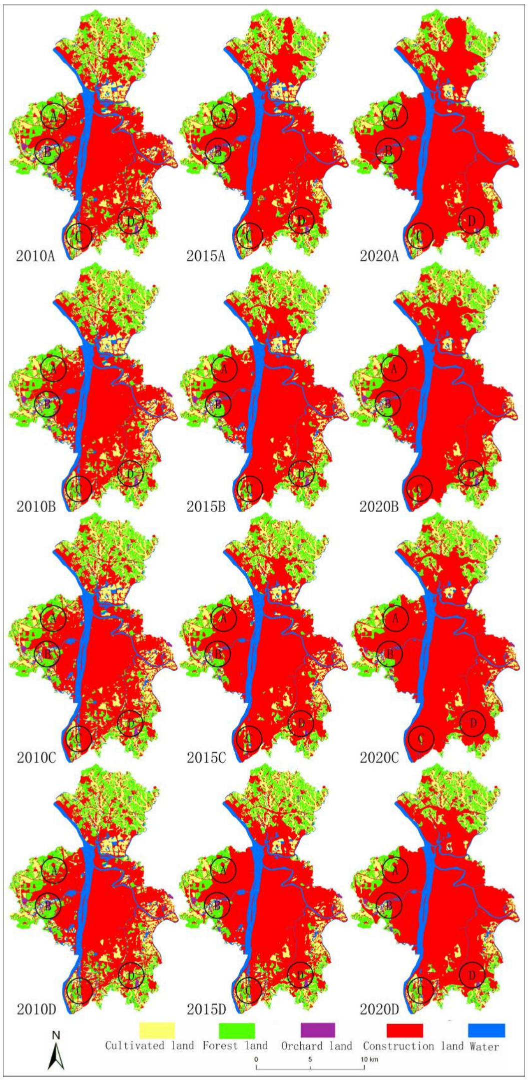

Figure 1. Simulation results of development trend of farmland conversion under different scenarios in Changsha from 2006 to 2020.