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Social and economic impacts of subsidy policies on rural development in the Poyang Lake Region, China: Insights from an agent-based model

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ABSTRACT

Further increasing grain production and rural household income is a major challenge for rural development in China, and the current small scale of farming operations is an important factor limiting progress on both. The Chinese central government's recent approach to promoting rural development addresses the role of land rental markets in facilitating larger-scale farming operations. We use an agent-based model that represents livelihood decision-making of rural households to explore the effects of an alternative policy that subsidizes rural households that rent out their land-use rights for long terms in comparison with the current policy of subsidizing grain producers. The model is built upon our empirical analysis of social surveys and interviews in eight villages around Poyang Lake. We consider policy impacts in terms of economic performance and equality. The modeling results suggest that policy responses differ considerably between villages with poor, average, and good farmland resources, and the rental-subsidy policy is expected to be most effective at stimulating land rental markets in villages with average farmland resources. The rental subsidies are likely to move the agricultural system to a more productive state with more growth potential and less cost in most places. The rental-subsidy policy can also make every household in farmland-poor places better off and may be used to further address inequality in farmland resources. However, both policies show limited effects on increasing rural income, suggesting rural development will continue to depend on urbanization. We discuss how the government may use the rental subsidy as an instrument to facilitate urbanization to best benefit all rural households.

1. Introduction

Since policy reforms began in the late 1970s, the Chinese economy has experienced dramatic growth. However, income and the living standard of rural populations have consistently lagged behind urban populations (NSBC, 2013). To promote rural development, the Chinese government implemented a series of policies (Heerink et al., 2007; Yu and Jensen, 2010; Long, 2014). During the initial reform period, rural income and agricultural production were marked by fast growth, mostly due to institutional innovations and particularly the implementation of Household Responsibility System (HRS) (Fan, 1991; Lin, 1992). Rural income, however, entered a stagnant period in the late 1980s. Though agricultural growth remained impressive for fishery, meat, vegetable, and fruit production in the period 1985–2005, the growth rate of grain production was low (Huang, Yang and Rozelle, 2010a, b). Beginning in 2004, agriculture taxes were eliminated and subsidies in the form of cash, high-quality grain seeds, and machinery have been made to households to stimulate grain production and increase farmer income. The recent approach of the Chinese government to promoting rural development, as described in a series of No. 1 Policy Documents issued by the Central Committee of the Chinese Communist Party from 2004 to 2013, reflects its continued commitment to strengthening farmer's land-use rights and the use of market-oriented mechanisms, including emphasizing the role of land rental markets in consolidating farmland and facilitating larger scale of farming operations.

Agricultural economists have also argued for the need to stimulate farmland rental markets in rural China as a means to improve land allocation efficiency (Yao, 2000; Deininger and Jin, 2005; Tu, Heerink and Xing, 2006; Jin and Deininger, 2009). Currently farming operations in rural China are small, partly due to limited farmland and partly resulting from the implementation of HRS in the late 1970s and early 1980s that followed the principle of equality, according to household size, the number of laborers in a household, or both, in farmland allocation. In addition to directly contributing to low agricultural income, the small farmland area discourages rural households from investing in

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agriculture and prevents the application of machinery, limiting the potential of agricultural output (Tan et al., 2010). Rural households can exchange land-use rights through private farmland rental markets, but the utilization and effectiveness of farmland rental markets vary across rural areas in China (Gao, Huang and Rozelle, 2012). Because farmland rental contracts are often informal and signed for short time periods, rural households do not have secure use rights over rental farmland, which discourages them from renting in larger areas. The inherent insecurity in such short-term informal contracts can also lead to declining investments in rental land (Yu et al., 2003; Cai et al., 2008; Gao, Huang and Rozelle, 2012). The Hukou registration system in China that differentiates urban and rural households also influences the decisions of rural households on how to deal with their farmland in the country side, further discouraging farmland exchanges (Liu, Fang and Li, 2014). Because migrant workers do not have the same social security and benefits as the urban population, many of them regard farmland as their safety net and do not intend to permanently settle in cities even if they do well in cities. This prevents them from exiting agriculture and releasing farmland to other households.

We use an agent-based model (ABM) to explore the potential effects of a policy that subsidizes households to rent out land-use rights for long terms under formal contracts (called "rental-subsidy policy") on promoting rural development. We expect that such a policy can stimulate farmland rental markets, increase the scale of farming operations and help secure land-use rights that are rented from land markets. Furthermore, it may encourage rural households that do well in cities to exit agriculture and release their farmland to households that intend to specialize in agriculture. ABMs are useful tools for simulating heterogeneous agents in complex systems to explain how local actions and interactions of agents give rise to system-level outcomes or macro patterns (Schelling, 1971; Axelrod, 1986, 1997; Epstein and Axtell, 1996; Janssen and Ostrom, 2006; Berger, 2001; Parker et al., 2003; Gilbert, 2008; Farmer and Foley, 2009; Walsh et al., 2013; Malanson et al., 2014). A number of studies have applied ABM for policy analysis (Bankes, 1993; Lempert, Popper and Bankes, 2003; An et al., 2005; Berger, Schreinemachers and Woelcke, 2006; Happe, Kellermann and Balmann, 2006; Robinson and Brown, 2009; Defourny et al., 2011; Schouten et al., 2013; Zheng et al., 2013; Quang, Schreinemachers and Berger, 2014). The benefits of using ABMs from policy analysis come from their ability to represent heterogeneous agents in a system and capture their different responses to policy interventions and interactions.

As rural households worldwide increasingly participate in urban economies and global economies amid urbanization and globalization, researchers in both land use and farming system research communities recognize an urgent need to examine individual farming systems within broader social, environmental, economic, and institutional contexts at multiple scales (Giller, 2013; Seto and Reenberg, 2014; Müller and Munroe, 2014; Whitfield et al., 2015; Tian et al., 2015). Because ABMs can represent the behavior of individual farming systems that have heterogeneous characteristics embedded within local social and environmental settings and broader development contexts, they are potentially useful for examining interconnections between urban and rural development and interactions between local and global contexts. Because of the cross-scale interactions, policy interventions may produce differential effects across local settings. An agent-based modeling approach is likely to generate further insights into how policies may need to vary across places to effectively promote social and economic development.

Our model is designed based on an empirical analysis of household surveys, qualitative interviews and participant observations we carried out in eight villages around Poyang Lake (Tian, 2011; Tian et al., 2015; Tian, Guo and Zheng, 2016). The Poyang Lake Region (PLR) is a major agricultural production base in Jiangxi Province composed of ten counties and two cities (Nanchang and Jiujiang). According to the Chinese Census in 2010, the total population in PLR was about 9.2 M, and 78.3% of the population outside the two cities was classified as rural. In 2010 the annual GDP per capita of Jiangxi Province was about 21,000 YUAN, 29% lower than the national average. Even though PLR is the most developed area in Jiangxi Province, the annual per capita net income of farmers was slightly below the national average of 5900 YUAN (Yan et al., 2013). As with other rural areas in China, rural livelihoods in PLR are extensively integrated with the urban economy. Based on our household surveys, on average, 65% of rural income was from non-farm sources in 2006. Rice is a major crop traditionally cultivated and still widely practiced today. Rice can be grown once a year, called one-season rice, or twice a year, called two-season rice. Due to increasing income from migratory work and the degradation of irrigation systems, two-season rice cultivation that was widely practiced in the region in the past has been converted to one-season rice in many places, which was also observed by Shi, Heerink and Qu (2011). Across surveyed villages except one village that has rich farmland, we observed that older people and some women were the major labor force present on the farm, and the overall efforts in crop cultivation were low.

We implement two policy scenarios in the model - subsidies to rice producers and subsidies to long-term renters (20 years) - to compare the potential effects of the rental-subsidy policy with the current policy that subsidies rice cultivation. We examine their multiple effects in three stylized villages with differing farmland resources. We look at their economic performance in increasing rural income and rice production. We examine the economic growth trajectory of the villages under these two policy scenarios to compare their potential in promoting continued growth. We also compare their possible role in addressing farmland resource inequality among villages. Additionally, we explore the effects of varying amounts of subsidy to renters in an attempt to identify "lever points," meaning relatively small changes to a system input or boundary condition that can produce large effects on the system (Holland, 1995; Holland, 1998).

In the following section, we describe our methods in detail, including the conceptual model, empirical data, model implementation, and our approach to model verification and validation. We then describe the experiments we conducted to explore policy effects. We present our experiment results and discussions on policy effects together. We also discuss the implications of model design and model assumptions on our conclusions.

2. Material and methods

2.1. The modeled system

The model simulates farmer households whose members engage in some combination of migratory work and rice cultivation (Fig.1). Our empirical analysis suggests that these households constitute the majority of rural households in PLR, and rural development can be defined in terms of the livelihoods of these households. Each household agent makes decisions about the amount of labor spent on agricultural work and migratory work. The household agents also allocate farmland area to growing one-season rice and two-season rice. They can interact with each other through a land rental market and sometimes exchange information, such as land rental prices. They carry out their livelihoods to different degrees of success, mostly determined by the availability of labor, capacity for and experience with agricultural and migratory work, and farmland endowments.

The wages for migratory work and prices for rice on the agricultural market are important factors that affect household decisions. Because our model simulates a system representing individual villages that have relatively little influence on grain and labor prices, and because we are interested in evaluating alternative policies under current levels of development, we treat wages and prices as exogenous.

Two kinds of feedback between individual decisions/actions and the global state of the system are modeled: (i) the decisions/actions of household agents collectively determine total farmland demand,

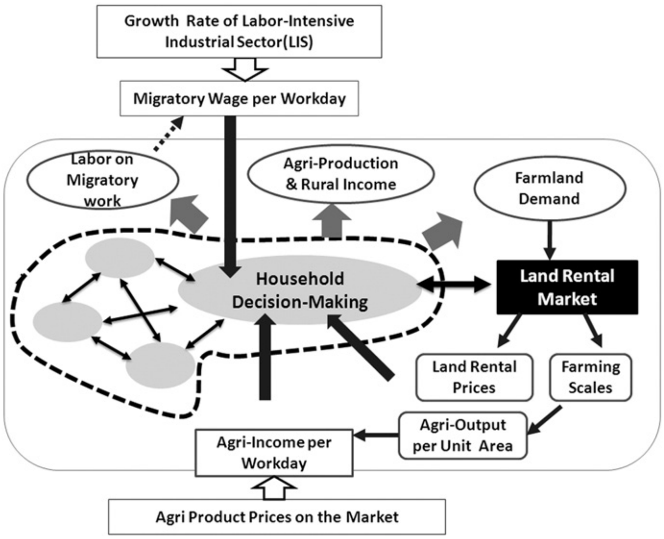

Fig. 1. Objects inside the large box are modeled as endogenous entities. Objects outside the box are exogenous but important to the decisions of households. Objects inside the dashed line represent household agents and their information networks. Double-headed arrows represent information flow and interactions between households on the market. Thicker solid black arrows illustrate what factors in the system affect individual household decision-making. Thinner black arrows indicate relationships between variables in the system. Thick gray arrows illustrate what collective outcomes result from the actions and interactions of individual household agents.

which affects land rental prices, and therefore subsequent decision making of household agents; (ii) total farmland demand also affects the farmland area each household agent can obtain, which constrains farming scales and agricultural productivity and ultimately the decision making of household agents.

We made several assumptions in the model. First, farmers in the model can always find migratory work at some wage if they want to work in cities. Second, farmer household agents do not hire labor. Third, rice yields increase as the area of farmland a household manages increases. Fourth, farmers' input use is not affected by subsidies. Fifth, the current grain subsidies are given based on actual area planted with rice. Sixth, all farmland rental contracts involve payments. The first assumption can be justified by the observed fact that most young and middle-aged villagers are doing migratory work and by the calibration of household migratory work efficiency function. For the fifth and six assumptions, we conducted additional experiments to check the robustness of our inferences on policy effects under scenarios that some farmland rental contracts are arranged between relatives and therefore do not involve payments, and grain subsidies are given based on contracted farmland areas. We discuss how the second, third and fourth assumptions may affect model results in the section on model limitations.

2.2. Empirical data

We used empirical data obtained from surveys, interviews, and field observations in three villages, which represent places with poor (V1), average (V2), and good (V3) farmland resources, as reference data (Table 1). The purpose was not to use these data to fit the model and simulate these three villages in detail, but to use them as reference points to explore policy effects in different kinds of places regarding the biophysical environment.

The empirical data were also used for model validation purpose. We compared observed values of several outcome variables at the village level with model outputs to test the model's ability to generate differences between places with different farmland endowments. The important general facts that guided the model validation were (see Appendix A0 and A1 for details): (i) in V1 and V2, there was a reduction in two-season rice after economic reforms began, with households currently emphasizing one-season rice; in V3, there was no obvious change, such that two-season rice still dominates; (ii) the average land rental price compared as follows V1 < V2 < V3; (iii) the proportion of income from migratory work compared as follows V1 > V2 > V3; (iv) a small portion of farmland was left fallow in V1, while farmland was mostly cultivated in V2 and V3.

The three villages also represent different situations that are associated with different rice yields, and we used these differences to calibrate the rice-yield functions with increasing scales of farming operations.

2.3. Major components of the model

2.3.1. Agents: rural households

Rural household agents each have an initial endowment of wealth, labor, and farmland and differ in their levels of ability regarding migratory and agricultural work, social interaction, and cognition (Table 2). They know the costs and labor needed per unit area associated with rice cultivation, as well as the price of rice on the market. Each year, they attempt to increase total income based on their past performances in migratory work and rice cultivation, as well as experiences with the land rental market.

The decision-making process of a household agent is represented as heuristic rules that are used to improve income over time, which is informed by our empirical analysis. The process is described with the following pseudo code (see Appendix-A2 for details).

1. Form its expectation on the land rental price per unit area
2. Estimate income from agricultural work per unit area by doing the following:

   If (engaged in agricultural work in the previous year):

      Calculate income per unit area using data from the previous year.

   Otherwise:

      Update its yields from past experiences with new information from other household agents.

      Calculate income per unit area based on newly estimated yields.
3. Estimate wage for migratory work per work day by doing the following:

   If (engaged in migratory work in the previous year):

      Calculate wage for migratory work based on data from the previous year.

   Otherwise:

      Update wage from past experiences with new information from other household agents.
4. Form a few plans (each plan includes labor allocated migratory work and farmland area allocated to one-season rice) by adjusting labor and farmland allocation, compare their economic returns and choose the plan that produces the greatest economic return
5. Compute the need for renting in/out farmland

   If (long-term rental subsidy is available):

      Make decision on whether to rent in/out for the long term.

2.3.2. Land rental market

The land rental market was implemented as a two-round exchange process. When subsidies for long-term contracts are not an option, the household agents that intend to rent in farmland begin first. They visit a number of randomly chosen households, with the number specified by a model parameter *NumHouseholdTrade* (described in Table 4). If a chosen household agent does not have a good social relationship with the household agent seeking to rent, with the chance determined by the social capability of the initiating household agent, no contract is made. If the price offered by the household agent that intends to rent

Table 1
General characteristics of three representative villages selected for use in setting model parameter values, calibrating rice-yield functions and comparing system outcomes in villages with different farmland endowments.

Characteristics		V1	V2	V3
Natural environment and farmland resources		Remote and isolated. Plots are hilly and highly fragmented with a small total area of farmland.	Plots are flat and about average in fragmentation and total area.	Plots are flat, less fragmented with a large total area.
Data relevant to rice yields	Soil fertility	Poor	Good	Good
	Efforts in crop cultivation	Poor	Average	Good
	Collective irrigation system condition	Poor (Destroyed. Can rent privately owned pumps with an hourly fee to get water from a pond.)	Poor (Similar to V1)	Good (Well maintained and functioning)
Data used for setting model parameters	Farmland area per household	3mu	7mu	13mu
	Average yield of one-season rice (kg per mu)	350	450	500
	Average yield of two-season rice (kg per mu)	500	600	800
Data relevant to model validation	Land rental price (YUAN per mu)	About 50 (small plots on hills are free)	Between 100 and 150	About 300
	Pct. non-farm income	76.6%	72.4%	47.6%
	Pct. two-season rice	8.5% (very little two-season rice)	0% (no two-season rice)	70% (with some one-season rice in low-lying areas)
	Pct. cultivated area	91.3% (some fallowed plots were observed, mostly small plots on hills)	100% (no fallowed plots were observed)	100% (no fallowed plots were observed)
	Land-use change	In the past, two-season rice was widely cultivated.	In the past, two-season rice was widely cultivated.	No major changes.

Note: 1 mu is about 0.067 ha. The rice yields used for setting model parameters in V1 and V2 are not strictly from the surveys. For a description on how we derived these numbers, please see Appendix-A1.

in is greater than the price asked by the chosen household, the deal is done at the price offered. Otherwise, if the difference between the two prices is within one tenth of the estimated farming income from a unit area for the household agent that intends to rent in, the deal is done at the average of the two prices. After the first round of exchange, if some household agents that intend to rent out still have farmland left unrented, they each randomly choose and visit several other household agents to negotiate rental contracts. Again, if the chosen household agent does not have a good social relationship, no contract is made. If the price asked by the household agent that intends to rent out is less

Table 2
Endowments and attributes of households in the model: description and range.

Endowment/attribute	Description	Distribution among households	Lower bound	Upper bound
Initial wealth	An initial endowment of wealth (in YUAN)	Uniform	5000	20,000
Labor amount	An endowment of labor (in persons)	Normal (3.6, 1.4)	1.0	7.0
Farmland area	Initially contracted farmland (in mu)	First assigned proportional to labor amount, and then adjusted to reflect demographic changes (described in detail in the section of model initialization.)		
Migratory work capability	A unitless multiplier on the average wage for migratory work set by model parameter *AvgWageInitial* (in YUAN per work day). For instance, if a household has a migratory work capability of 0.8, its first member sent to do migratory work gets paid at 0.8 ∗ *AvgWageInitial* per workday. Migratory work capability of subsequent household members is modeled by a migratory work efficiency function (Fig. 2).	Normal (1.0, 0.2)	0.5	1.5
Agricultural work capability	A unitless multiplier on the average yields in a village set by two model parameters *AvgAgriOutput1sRiceInitial* for one-season rice and *AvgAgriOutput2sRiceInitial* for two-season rice.	Normal (1.0, 0.1)	0.5	1.5
Social capability	Percentage of households with whom a given household has good relations, affecting the probability of success in negotiating land-use-right rental contracts. For instance, a social capability of 0.8 means a household having good relations with 80% of the households in the village, and it will fail in negotiating land-use-right rental contracts with a chance of 20% if model parameter *SocialEffects* is set to true.	Normal (0.75, 0.1)	0.5	1.0
Cognitive capability	Determines how many livelihood plans a household forms and evaluates. The average number is set by model parameter *AvgNumPlans*.	Uniform	*AvgNumPlans*-2	*AvgNumPlans* + 2

Note: The two values associated with normal distributions are mean and SD. In general, the households do not differ greatly in all these capabilities. A standard deviation of 0.2 for migratory work capability reflects a larger spread among households in migratory work. The parameters of labor amount are set based on the survey data (see Appendix 5-A1 and 5-A2). Model parameters are described in detail in Table 5-3.

than the price offered by the chosen household agent, the deal is done at the price asked. Otherwise, the deal is done at the average of the two prices if the same condition used in the first round is met.

Under scenarios in which long-term contracts with subsidies are an option, household agents that intend to rent out for the long term begin the process first because of the subsidy incentive. They each visit five more households than they would visit for yearly contracts. If the price asked by the household agent that intends to rent out is less than the price offered by the chosen household agent, the deal is done at the price asked. Otherwise, if the price asked by the household agent that intends to rent out is no < = 5% of the price offered, the deal is done at the average of the two prices. Then, the household agents that intend to rent in land-use rights through long-term contracts and whose needs have not been fully met sample household agents looking to rent out. After two rounds of exchange through long-term contracts, the household agents update their remaining demands on yearly contracts. Those household agents whose needs for long-term rental are not met, and those household agents that have decided to rent in/out land-use rights yearly perform another two rounds of exchange and make yearly contracts.

2.3.3. Migratory work efficiency function

We used an efficiency function (Fig. 2) to capture the different levels of labor quality for a household agent's migratory work. This represents our observations in the field that the first people from the household to enter the urban labor market are of the highest quality (e.g., young men and women with higher skills and/or education), and with every increment of household labor spent on migratory work, the marginal economic return decreases because the quality of labor decreases (i.e., includes lower skilled and less capable workers).

The function, based on empirical data, uses the following equation: $Y = (1 - x)^p$ where $p = 1/2$ when $x \le 60\%$; $p = 1$ when $x > 60\%$; x is the percentage of labor a household agent spends on migratory work. Averaged across the three villages, the survey data indicate the following age composition of the labor force: 60% are age 15–40; 36% are age 40–60; and 4% are over 60. Because people older than 40 years are not very competitive in migratory work, the marginal return decreases sharply at that point. Other values of p for $x \le 60\%$ (1/3 and1/4) were also tested. Setting p to 1/2, produced values of the outcome variables at the village level that were closest to the empirical data.

2.3.4. Yield functions

Rice yield per unit area is determined by several major factors: fertility of farmland, quality of the irrigation system, management efforts, and machinery usage and other technology. The forms of the rice-yield functions (Fig. 3) reflect the effects of changes in effort and capital investments as the area of farmland managed by a household agent increases. Δ1 reflects the increase in yield associated with increased efforts when the area of farmland managed by a household agent reaches 10mu. The survey data suggest that farmer households in V3 where the managed area on average is over 10mu apply more labor to crop cultivation and achieve higher yields per unit area. Δ2 reflects the increase in yield associated with the improvements in the irrigation system when the area of farmland managed by a household agent reaches 30mu. When a household manages 30 mu of farmland, the household can make a yearly income similar to the income from migratory work if it grows two-season rice. Therefore, it is worth investing in irrigation system improvements. A much larger value of Δ2 for two-season rice than one-season rice reflects the limits households face in irrigating fields for two seasons without the aid of a functioning irrigation system. The positive slopes of both lines reflect a constant increase in yield as a result of steadily increasing efforts a household agent puts in crop cultivation as its farmland area increases.

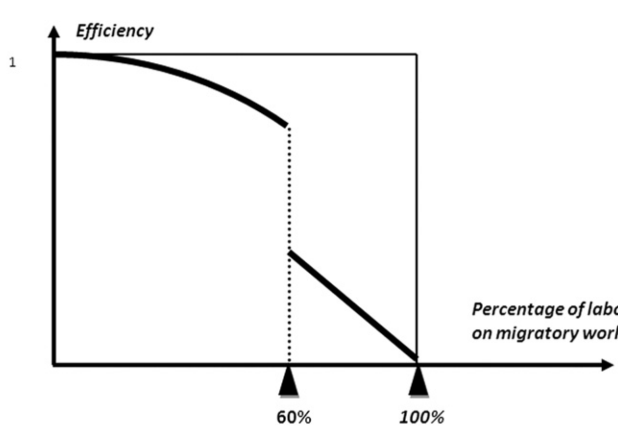

Fig. 2. Migratory work efficiency function. For each additional unit of labor a household agent spends on migratory work, its marginal economic return decreases.

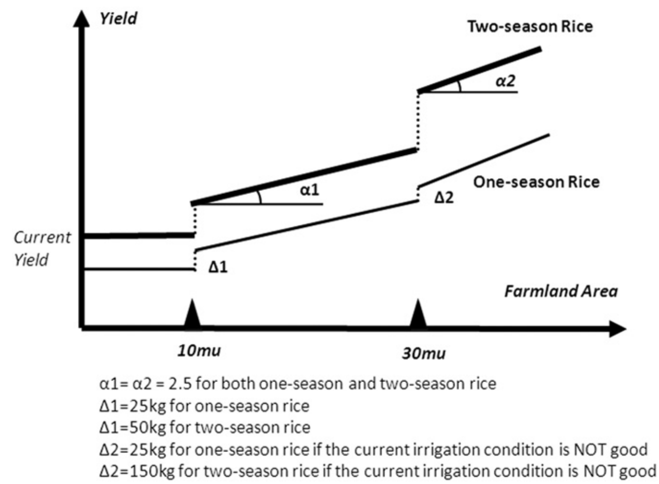

Fig. 3. Rice yields as a function of the area of farmland managed by a household.

We used observed yield differences in three villages (Table 1), which reflect differences in farmland fertility, irrigation system condition and management efforts, and other published information to calibrate yield functions (Fig. 3) for our three stylized villages in the model. The potential yields at larger scales of farming operations were first estimated for each village (Table 3). Rice farming in these villages uses traditional methods and varietals, with little mechanization, and there are multiple and specific ways to improve rice yields in Jiangxi (Pan, 2008; Shen and Xu, 2009; Zhou, 2011). New varietals have been reported to yield 675.3 kg per mu and 1300 kg per mu for one-season and two-season rice, respectively (*China Science and Technology Daily*, November 03, 2009). Even our largest estimates of yield per mu in V2 and V3 (550 kg/850 kg) are conservative. The potential yields in the three villages at the scale of 30 mu were estimated such that they only reflect the differences in farmland fertility. Based on these yields, we estimated the values of α1, α2, Δ1 and Δ2 as shown in Fig. 3.

2.3.5. Model parameters and initialization

We describe the major model parameters in Table 4. The default values are used unless specified otherwise in the model experiments.

At the beginning of each model run, 100 household agents are created to reflect approximately the average size of a natural village (i.e., the smallest level of social organization) in this part of China. Each household agent is assigned an initial amount of wealth, labor, farmland area, and capabilities as described in Table 2. Household agents are first assigned land-use rights for an area of farmland that is proportional to that household agent's labor amount. Because land-use rights in the region are currently distributed inequitably due to demographic changes since they were first assigned to individual households in the late 1970s, the land areas in the model are then adjusted randomly

Table 3
Current average yields and potential yields at larger scales of farming operations.

Village	Fertility	Collective irrigation system condition	Efforts	Current yield (kg per mu)		Potential yield (At 10-mu scale)		Potential yield (At 30-mu scale)	
				One-season rice	Two-season rice	One-season rice	Two-season rice	One-season rice	Two-season rice
V1	Poor	Poor	Poor	350	500	375	550	450	750
V2	Good	Poor	Average	450	600	475	650	550	850
V3	Good	Good	Good	500	800	500	800	550	850

reassigning either 1/2, 1/3 or 1/4 of the farmland from half of the household agents to other randomly selected households in the village.

2.4. Model verification and validation

To make sure the model was built appropriately and did not include important programming errors (i.e., verification), we followed some general rules of model development. We started with a very simple structure and gradually added more components. We also used many extreme cases to test the program (An et al., 2005). The computer model was developed on the .NET version of the Repast platform using C#. The Repast platform provides a user interface for setting model parameter values (described in Table 4). It allows us to run the model interactively and conduct experiments in a batch mode.

We ran the model interactively numerous times to observe the behaviors of the system before running systematic experiments described below in batch mode. These observations also informed the design of the experiments. For example, through interactive model runs, we noticed that the system never reaches equilibrium, but it does settle into a quasi-equilibrium pattern after about 10 steps, i.e., the average rental prices and other system-level variables do not fluctuate substantially but remain within a limited range of values. On one hand, this pattern characterizes the current stagnant state of rural development, which increases our confidence that the model plausibly describes overall system behavior. On the other hand, it provides input for our decision about the number of steps needed for systematic experiments, and how to use the values of the system-level variables to represent the state of the system.

We attempted to increase the confidence level of our model by conducting validation at conceptual, micro, and macro levels (Robinson, 1997; Grimm et al., 2005; Brown et al., 2008). Our empirical analysis of household social surveys and interviews in PLR offers insights into the key elements and the dynamics of the system. The survey also provides data for micro and macro-level validation. We used survey data at the micro level to calibrate model parameters and initialize the model when it was applicable, as described above. We then validated the model at the macro level using three different processes described in detail below.

2.4.1. Matching multiple macro-patterns

The first validation exercise tests the model's ability to reproduce differences in several outcome variables among surveyed villages. For each of the three villages, we ran the model 100 times with 25 steps each time. The 25 steps were divided into a 20-step period in which the current policy of subsidizing rice cultivation was not implemented, and a five-step period in which the current policy was in effect. At each step, we recorded the values of four variables: average land rental price per unit area, percentage of non-farm income (non-farm income /

Table 4
Model parameters: description and default value.

Parameter group	Parameter name	Description	Unit	Default value	Experimental values
Agricultural market	*PriceOfRice*	Rice price on the market	YUAN per kg	2 (current level)	
Industrial sector	*AvgWageInitial*	Average wage for migratory work	YUAN per work day	40 (current level)	0.5 (past level, used in the experiments on land-use change)
Agricultural sector	*AgriSmallScale*	Size of farmland managed by a household, below which is considered small-scale farming	mu	10	
	AgriLargeScale	Size of farmland managed by a household, above which is considered large-scale farming	mu	30	
	CostCrop1	Cost associated with fertilizer use and other inputs for one-season rice	YUAN per mu	300	
	CostCrop2	Cost associated with fertilizer use and other inputs for two-season rice	YUAN per mu	600	
Policy-related	*SubsidyCrop1*	Subsidy to one-season rice cultivation	YUAN per mu	0	50 (current policy)
	SubsidyCrop2	Subsidy to two-season rice cultivation	YUAN per mu	0	100 (current policy)
	SubsidyRenter	Subsidy to long-term renters	YUAN per mu	0	40–800 (rental-subsidy policy)
Household behavior	*AvgNumPlans*	Average number of land-use and livelihood plans households form and evaluate		5	
	NumHouseholdTrade	Number of households a household visits to negotiate land-use-right contracts		6	
	SocialEffects	Whether social relations affect the success of land-use-right rental deals (when set false, this social effect is ignored)		True	
Village-specific	*AverageArea*	Average area of farmland per household	mu	Set as described in Table 5-1 for the three villages respectively.	
	Irrigation system	Condition of the collective irrigation system	1: Good 0: Poor		
	AvgAgriOutput1sRiceInitial	Average yield of one-season rice	kg per mu		
	AvgAgriOutput2sRiceInitial	Average yield of two-season rice	kg per mu		

total income * 100), percentage of area in two-season rice (area planted in two-season rice / total cultivated area * 100), and percentage of cultivated area (total cultivated area / total farmland area * 100).

We computed the mean value for each of these variables over the last five steps from each model run and calculated the mean and standard deviation of these mean values for each variable across all the model runs (Table 5). It has only been five years since the subsidy policy was implemented, and interactive model runs show that the system adjusted to its effects during this period. Therefore, we also report the mean value and standard deviation of each variable in the last step as well (Table 5).

The same relative values were obtained for all the outcome variables across the three villages, using both five-year averages and the last year value, as those observed in the surveys, interviews, and field observations (Table 5; Table 1). The measures in the last step are closer to the empirical data than the average measures over the last five steps, indicating that the modeled system is moving toward the empirical observations during the five-step period. Interactive model runs also demonstrate that, in general, average land rental prices exhibit an increasing trend in each village in the last five-step period. This trend reflects the effects of the subsidy for crop cultivation, and thereafter, the system settles into a state of quasi-equilibrium. These results and observations suggest that the model captures the dynamics of the real system reasonably well. Though we cannot establish the absolute link between a step in the model and a year, the validation results suggest that they are reasonably comparable and adequate for questions about long-term outcomes.

The most noticeable disagreement between modeled outcome and the empirical data is the percentage of non-farm income in V1. We suspect inaccuracies in the social survey in this case. V1 is the most traditional among all surveyed villages, in that it still maintains production of many minor crops out of routine, even though it draws significant income from migratory work. Villagers in such places may tend to report less income from migratory work. From our five-day stay in V1, it is obvious that the villagers largely rely on migratory work for their livelihoods, and the production of many crops is mostly for household consumption. In another surveyed village, which has poor farmland resources similar to V1, the percentage of non-farm income based on the surveys was 89.58%, which is closer to the model results. It could also be because the model does not represent other elements in the decision making process, such as traditional values, social capital and the ability to cover the initial costs of migration which are considered important for migration decisions (Taylor and Martin, 2001).

2.4.2. Reproducing land-use changes

The second validation exercise tests the model's ability to recreate historical land-use changes as indicated by the household interviews. We conducted two experiments: one for a scenario in which there was very little opportunity for migratory work, similar to the period prior to economic reforms (with *AvgWageInitial* set to 0.5 YUAN), and one for a scenario in which migratory work was widely available, as in the mid-2000s (with *AvgWageInitial* set to 40 YUAN). Because the yields of rice (two-season rice in particular) in V1 and V2 have been affected by the degradation of irrigation systems, we additionally experimented with values of yield that represent the likely higher yields in the past in V1 and V2.

For each of the three villages, we ran the model 100 times with 20 steps each time for each parameter setting. At each step, we recorded the percentage of area planted with two-season rice. We computed the mean of the recorded values over the last five steps for each model run, and then averaged the means from all the model runs. We also calculated the standard deviations of the means over all the model runs.

The model produced larger proportions of two-season rice in V1 and V2 under past wage levels compared to those currently in place, even with rice yields set to the same values as observed in the present (Table 6; Table 7). This is consistent with the major land-use change that happened in these two villages, i.e., the conversion of two-season rice to one-season rice. With the likely higher yields of the past in V1 and V2, the changes in proportion of two-season rice from model simulations became larger, which is more reflective of what happened historically. Also consistent with empirical data, the model experiments show very little change in percentage of two-season rice in V3: the means are 95.3% (SD = 0.98) in the past and 94.5% (SD = 1.22) in the present.

2.4.3. Behavior of the modeled land rental market

Because the land rental market is an important component of the model, the third exercise tests the behavior of this component. We conducted a series of experiments to explore how modeled land rental prices respond to changes in total farmland area, yield of two-season rice (farmland productivity), and migratory work wage. We set the model parameters by varying each of the three variables, while keeping the values of the other two unchanged. The baseline values used for total farmland area, yield of two-season rice, and migratory work wage were 700 mu, 600 kg per mu, and 40 YUAN, respectively. They represent a place with average farmland resources and farmland productivity at the current level of wage for migratory work (i.e., the same as V2).

For each parameter setting, we ran the model 100 times with 20 steps each time. At each step, we recorded the average rental price. We computed the mean in the last 5 steps for each model run and then calculated the average and standard deviation of the means over all the model runs.

The experiments show that modeled average land rental price rises as land productivity increases, falls as migratory work wage increases, and rises as total farmland area decreases (Fig. 4). These relationships conform to the basic economic theory that the price of a good is determined by the relative quantity in total supply and demand, and the smaller the supply or the larger the demand, the higher the price (Varian, 2002). As total farmland area decreases, the total supply of farmland shrinks. As wages for migratory work go up, more farmers will be doing migratory work, which reduces the overall demand for farmland. Similarly, increased land productivity creates higher demand for farmland.

Table 5
Means (and standard deviations) for values of multiple system-level variables produced by the model and compared to empirical data.

Village	Avg. rental price (YUAN per mu)			Pct. non-farm income			Pct. two-season rice			Pct. cultivated area		
	Model		Interview	Model		Survey	Model		Survey/field observation	Model		Survey/field observation
	Avg. 2nd Prd.	Last step		Avg. 2nd Prd.	Last step		Avg. 2nd Prd.	Last step		Avg. 2nd Prd.	Last step	
V1	34.3 (5.6)	45.2 (6.7)	About 50 (bad plots are free)	93.6 (0.5)	93.9 (0.5)	76.6	21.1 (5.6)	9.6 (4.0)	8.5 (very little two-season rice)	92.7 (4.3)	87.4 (6.5)	91.3 (some fallowed plots)
V2	102.3 (14.4)	128.6 (18.6)	Between 100 and 150	76.5 (1.3)	76.8 (1.3)	72.4	11.7 (2.7)	9.5 (2.1)	0 (no two-season rice)	98.7 (1.2)	98.3 (1.5)	100 (no fallowed plots)
V3	255.9 (36.7)	339.5 (41.7)	About 300	41.4 (2.8)	42.7 (3.0)	47.6	94.9 (1.0)	95.2 (0.1)	70 (with one-season rice in low-lying areas)	99.4 (0.8)	99.1 (1.1)	100 (no fallowed plots)

Table 6
Modeled land-use changes in V1.

Yield of one-season rice		350	400			450		
Yield of two-season rice		500	600	650	700	600	650	700
Pct. two-season rice	At the past wage level	48.5 (7.18)	91.4 (2.61)	97.6 (1.30)	97.9 (1.18)	42.4 (7.16)	87.8 (3.35)	97.9 (0.97)
	At the current wage level	13.4 (5.78)	49.5 (7.18)	94.1 (2.10)	96.2 (1.25)	4.0 (1.36)	20.6 (4.77)	94.5 (2.10)

Note: Cells with a darker background indicate values of percentages of two-season rice with rice yields set to the same values as observed presently, while those with a lighter background represent more likely scenarios regarding rice yields in the past. Values inside parentheses are SD.

2.5. Policy experiments

We ran two policy-related experiments to (i) evaluate the current policy of subsidizing rice cultivation (50 YUAN per mu for one-season rice and 100 YUAN per mu for two-season rice), and (ii) explore the potential effects of a rental-subsidy policy that subsidizes long-term renters with different amounts of subsidy (starting at 20 YUAN per mu up to 800 YUAN per mu with an increment of 20 YUAN per mu each time).

We measured policy effects in terms of (i) changes in the state of the system, mainly in rural income and agricultural production system, (ii) economic efficiency, (iii) equality, and (iv) trajectory of the agricultural production system and income over time, indicating possibility for future growth. We used multiple outcome variables to represent the state of the system, including (i) total rural income, (ii) total rice production, (iii) percentage of cultivated area, (iv) percentage of farmland in two-season rice, and (v) percentage of farmland managed by the top 10 households. While the second of these variables reflects overall development of the agricultural system, the third, fourth and fifth further describe various aspects of the agricultural system in its extent and intensity of farmland utilization and scale of farming operations. We used two measures to evaluate the economic efficiency of policies: (i) increase in total rice production per unit cost and (ii) increase in total income per unit cost.

For each of the three stylized villages, we ran the model 100 times for each policy and subsidy amount with 40 steps each time. The 40 steps are divided into two 20-step periods. The first 20-step period serves as the baseline for measuring the effects of a policy implemented in the second 20-step period. At each step, we recorded the values of the five state variables and, in the second period, the total cost (government subsidy amount). A sample report file can be found in Appendix A3.

To examine the state change under the policies, we averaged the values of each of the five state variables over the last five steps and compared them with those over the last five steps in the first 20-step period for each model run. Additionally, we computed the rates of change for total rice production and total income and changes in percentage of cultivated area, percentage of farmland in two-season rice, and percentage of farmland managed by the top 10 households. We then calculated the mean and standard deviation of change/change rate for each state variable over all model runs. Using change rages of state variables instead of absolute values to measure policy effects can avoid the complications of different system starting points and their consequences due to the path-dependence of complex systems.

To measure the economic efficiency of the policies, we summarized total rice production, total income, and total cost in the second 20-step period for each model run. We computed total rice production and total income without the policy by multiplying the average values of these variables over the last five steps in the first period by 20. The differences in these measures were calculated to represent the total increase in rice production and total increase of income as a result of the policy. We then calculated agricultural efficiency by dividing total increase of rice production by total cost, and calculated income efficiency by dividing total increase of income by total cost. We calculated the average and standard deviation for agricultural efficiency and income efficiency from all model runs.

To examine the trajectory of the system under the policies, we first computed changes/change rates of the state variables at each step in the second period, relative to the end state in the first period for each model run, based on the same model runs for exploring the effects of policies as described above. The end state in the first period is represented by the mean values of the state variables over the last five steps in the first period. We then classified the changes/change rates at each step into several categories (called levels), where each level represents a 10% change along each dimension. We used the most frequently encountered level across all model runs to represent the state of the system at a step.

Table 7
Modeled land-use changes in V2.

Yield of one-season rice		450				500		
Yield of two-season rice		600	700	750	800	700	750	800
Pct. two-season rice	At the past wage level	45.5 (6.46)	95.4 (1.19)	95.7 (0.99)	95.9 (0.95)	81.7 (3.99)	95.1 (1.24)	95.8 (0.89)
	At the current wage level	7.3 (1.87)	89.3 (2.63)	93.8 (1.58)	94.4 (1.07)	20.7 (4.36)	88.1 (3.07)	93.9 (1.28)

Note: Cells with a darker background indicate values of percentage of two-season rice with rice yields set to the same values as observed presently, while those with a lighter background represent more likely scenarios regarding rice yields in the past. Values inside parentheses are SD.

3. Results and discussion

3.1. Effects of the current policy

Comparing the results from model runs with different amounts of subsidy for long-term renters (Fig. 5), we see that the effects of the current policy on rural development are overall limited, though with some differences across villages. Its largest positive effect appears to be increasing the extent of farmland use in V1 that has scarce and marginally productive farmland, but the increase in land-use extent in V1 only leads to small increase in total rice production because of poor farmland resources (Fig. 5a; Table 8).

The increase in land-use ex-tent in vil-lages with poor farm-land resources, as in V1, can be explained by low farmland profitability there: the subsidy makes farming a little more profitable on the marginal land. In villages with average farmland resources, as in V2, the subsidy produces minimal positive changes in the agricultural sector, both in terms of total agricultural production and the extent and intensity of farmland utilization in model simulations. In villages rich in farmland resources, as in V3, the subsidy does almost nothing to improve the agricultural sector in model simulations. This outcome can be explained by the high productivity of farmland in V3: households in such villages would grow two-season rice and make full use of their farmland regardless of the subsidy. Across all the villages in model simulations, the subsidy slightly decreases the scale of farming operations, and therefore, the potential of farmland may not be fully realized.

The current policy slightly increases total income in V3 in model simulations due to large government subsidies. In V1 and V2, subsidies to rice cultivation slightly reduce total income in model simulations, probably because the subsidy increases farming income, attracts more labor to remain on the farm and increases competition for farmland.

According to the model simulations, the current policy has small economic efficiency in both measures (Fig. 5b; Table 8). And it is not equitable: places rich in farmland resources receive a large amount of subsidy in addition to their inherent advantages in natural endowments, while farmers living in places with poor farmland resources receive much less subsidy and are left to seek migratory work (Fig. 5c; Table 8).

The simulated system trajectories suggest that the current policy has immediate effects that level off quickly (Fig. 6). The simulated system settles into quasi-equilibrium quickly and indicates no potential for

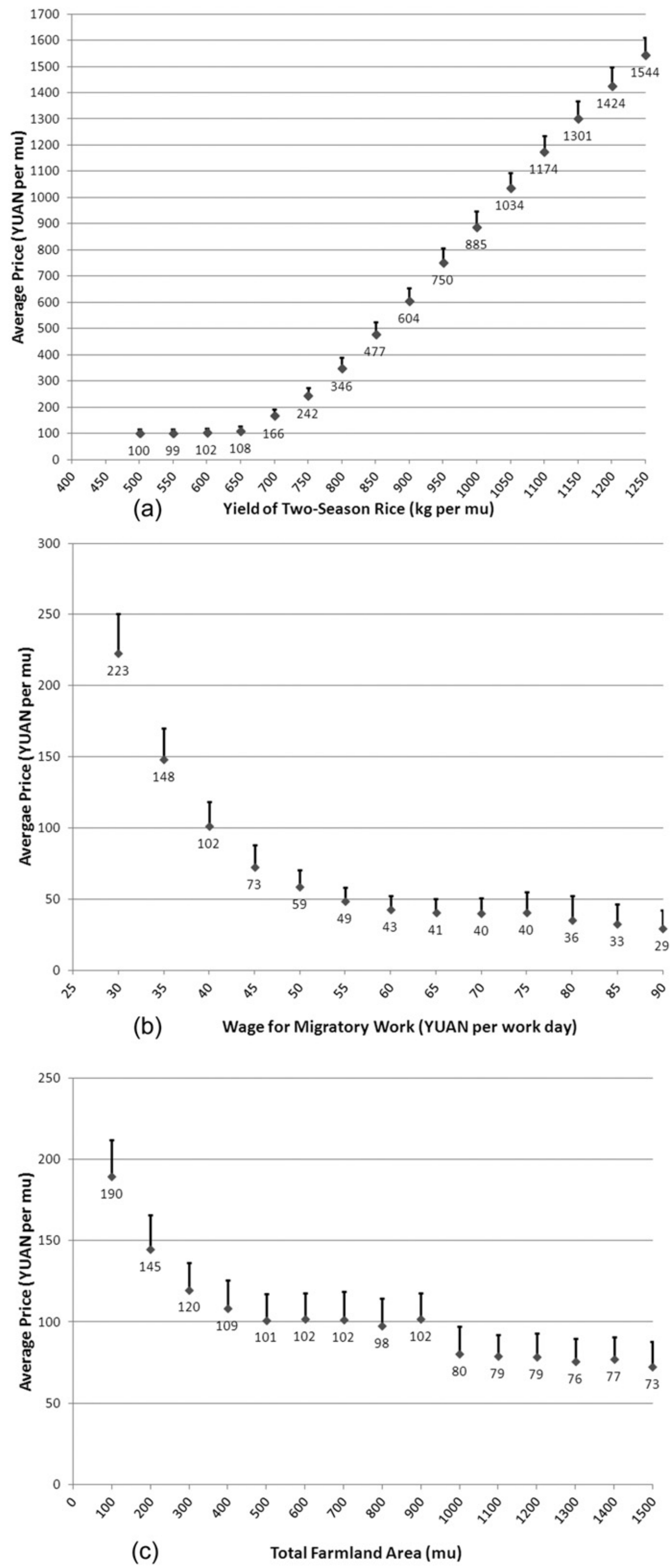

Fig. 4. Average land rental prices computed in the model under different settings of (a) farmland productivity, (b) wages for migratory work, and (c) farmland area. The bars indicate SD.

further growth. Note that our model does not examine other policy instruments, such as price supports, that the Chinese government has been using to promote rural development.

Because the major goal of this study was to explore the potential effects of the rental-subsidy policy, we compared its effects with the current policy in different settings in relative, not absolute, terms. Also for this reason, we did not intend to and could not compare our results quantitatively with other assessments of subsidies to grain producers. Very briefly, several previous studies using other methods also suggest that the current subsidy policy has limited or no impact on increasing grain production and farmer income (Gale, Lohmar and Tuan, 2005; Heerink, Kuiper and Shi, 2006; Huang et al., 2011). However, Yu and Jensen (2010) found that the grain subsidy program has increased grain production and farm income when the subsidy is linked to grain production. Xu, Wang and Shi (2012) showed that the tax elimination and subsidy policy has significantly improved farmer household income, though to different degrees in different provinces. Meng (2012) found that the grain subsidy can keep farmers from engaging in migratory work, indicating that it may improve grain production. Yi, Sun and Zhou (2015) found that the grain subsidy can increase grain planting areas for liquidity-constrained households. Our interviews of farmers and field observations suggest that subsidies to rice producers in general are not large enough to alter the relative economic returns from rice cultivation and non-farm income, and therefore we should not expect a significant impact on grain production, agreeing with Gale, Lohmar and Tuan (2005). Through our conversations with farmers, we learned that the grain subsidy policy does make farmers feel that the government cares about them and therefore has a positive social effect.

The different inferences on the effects of grain subsidies found in the literature may be influenced by research methods. Most of these studies use an econometric approach. Econometric models, e.g., Yi, Sun and Zhou (2015), are powerful in identifying general patterns, especially when large, representative samples are used. However, they generally lack in-depth understanding of causal mechanisms. Another type of analysis, e.g., Heerink, Kuiper and Shi (2006), uses general equilibrium models to simulate household decisions under different scenarios. Such models can include a broad range of economic activities and variables and separate the effects of a policy from other influences, such as price changes. General equilibrium models treat a household's decision making independent from other households and often examine a representative household that is assumed to optimize some objective function. ABMs directly simulate the decision making of heterogeneous households and very importantly the interactions among households. Therefore, ABMs can provide the micro-level mechanisms that are lacking in econometric models. For example, our model helps explain how grain subsidies negatively affect migration, a correlation found by Meng (2012). Compared with general equilibrium models, ABMs account for interactions and potentially social influences on individual household decision making. ABMs can also represent decision making more realistically and relax the assumption of complete rationality. Our model results agree with Heerink, Kuiper and Shi (2006) in that grain subsidies are not increasing production, because the interactions of households in the land rental market are not very important under the grain subsidy policy, though they are critical for examining the effects of the rental subsidy policy.

The advantages of the agent-based modeling approach however also create difficulties. ABM modelers need to consider many elements in a real system, and model abstraction remains a major challenge. The mechanisms represented in ABMs are perceived by some to be simplistic. For example, our model does not include the full range of household activities and variables. ABMs can be realistic and even implement households as rational agents and incorporate all the options and variables that general equilibrium models examine, e.g., Berger, Schreinemachers and Woelcke (2006). In fact, ABMs exhibit a gradient of level of abstraction, ranging from extremely abstract to extremely realistic representations. Schelling's classic segregation model (1971) and Axelrod's famous ABMs on culture dissemination and cooperation (1986 and 1997) are examples of extremely abstract models that generate profound insight about social dynamics. As an example of extremely realistic ABM, An et al.'s model (2005) represents every household in

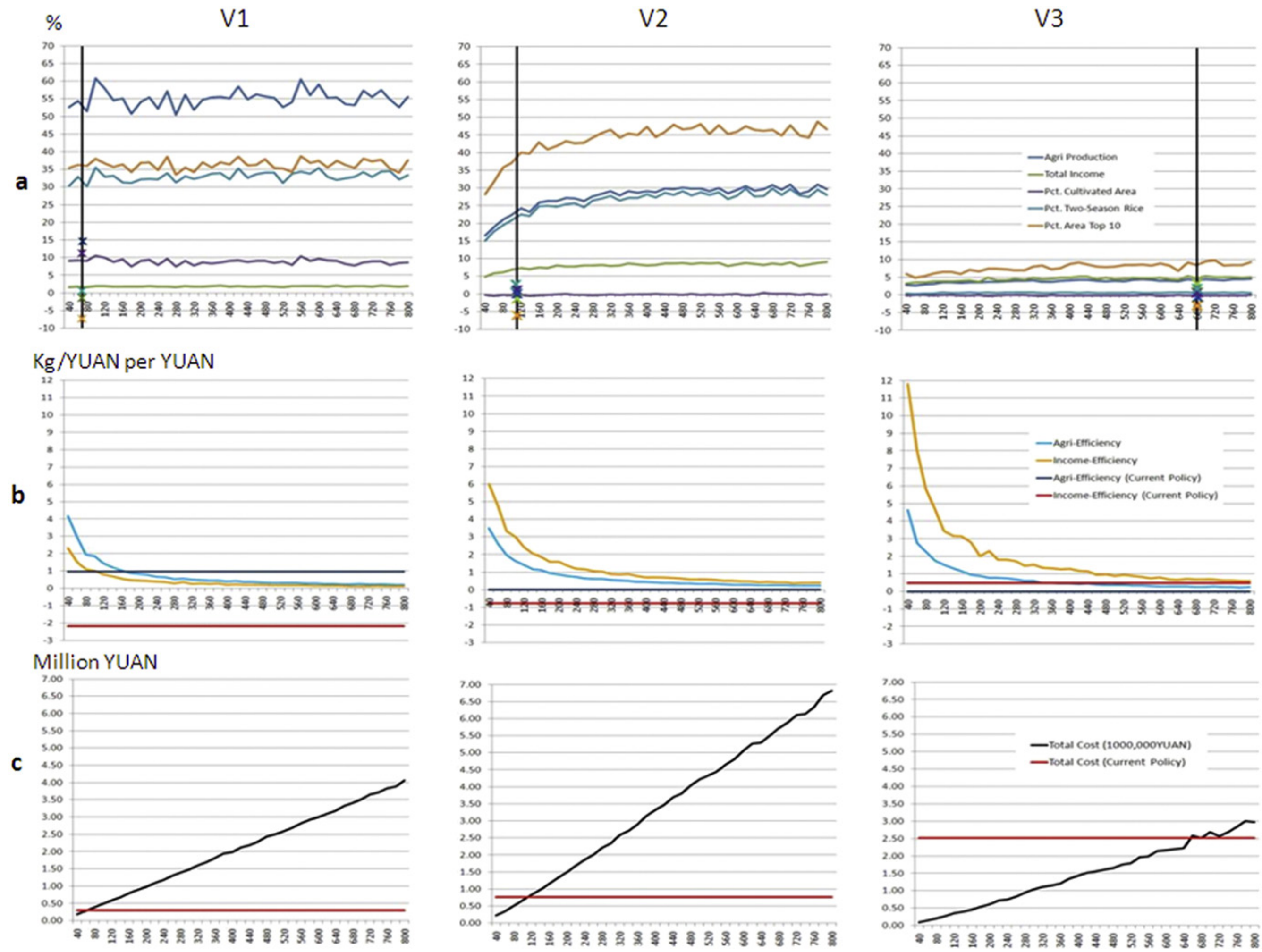

Fig. 5. Effects of the current policy and the rental-subsidy policy on (a) changes in system state; (b) economic efficiency; and (c) cost and equality. The vertical lines in (a) represent the amount of subsidy to renters that makes the total subsidy to a village about equal to what it receives under the current policy. The symbols x indicate the change in the state of the system resulting from the current policy. Data associated with this figure can be found in Appendix A4 through A6.

the Woolong Nature Reserve and a full range of demographic and economic dynamics to examine the influence of human activities on the giant panda habitat. Because of its realism, the authors are able to interpret and compare their modeling results with other models in absolute quantitative terms, whereas most ABMs look at trends and discuss results in relative terms. It is important to point out that as the level of details that are specific to a system increases in an ABM, its ability to make general inference decreases. Another argument against agent-based modeling is its intractability, and more details make it even more difficult to understand model outcomes (Axtell and Epstein, 1994). In addition, ABMs can be overly fitting (Brown et al., 2005), and similar to mathematic models (Gigerenzer and Brighton, 2009), increasing details in a model lead to better fit, but its prediction ability may decrease with too many details. We believe that a good ABM captures the key

Table 8
Comparison between the effects of the rental-subsidy policy and the current policy with a subsidy amount that results in a total amount of village subsidy about equal to what is currently received.

		V1		V2		V3	
Aspect	Measures	Renter (60 YUAN)	Current policy	Renter (110 YUAN)	Current policy	Renter (680 YUAN)	Current policy
Changes in the state of the system (%)	Agricultural production	54.41	14.77	22.98	0.08	4.06	−0.09
	Total income	1.73	−1.37	7.08	−1.24	4.72	3.01
	Pct. cultivated area	9.23	13.30	−0.32	0.85	−0.15	0.41
	Pct. two-season rice	32.89	0.91	21.68	2.27	0.48	0.57
	Pct. area top 10	18.03	−3.99	12.58	−2.22	2.27	−0.81
Economic efficiency	Agri-efficiency (kg per YUAN)	2.93	0.96	1.51	0.02	0.24	−0.01
	Income-efficiency (YUAN per YUAN)	1.50	−2.19	2.78	−0.77	0.68	0.46
Total Cost (YUAN)		282,270	291,905	739,247	755,955	2,517,222	2,513,998

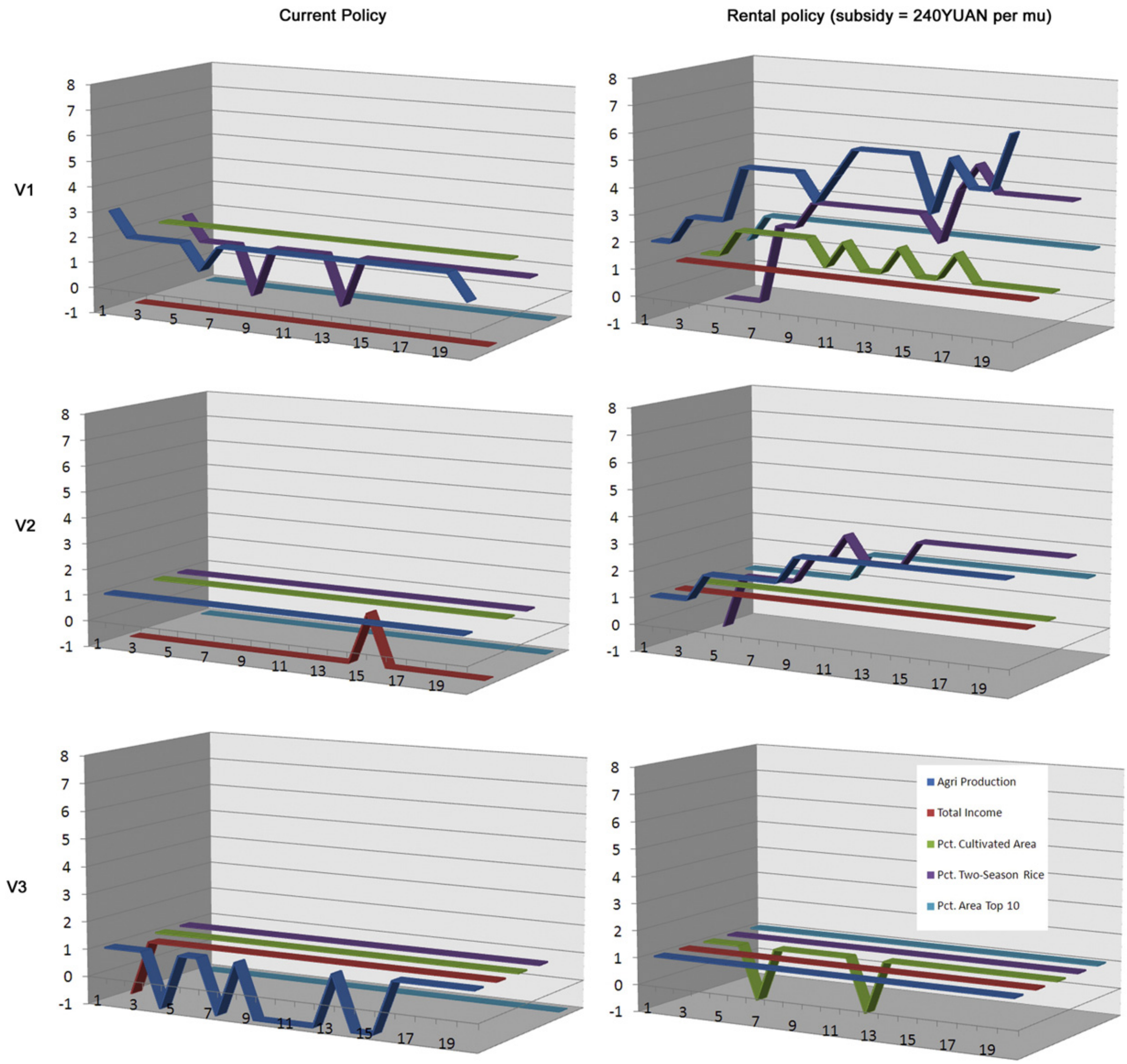

Fig. 6. Trajectories of the system. The horizontal axis is model run step in the second 20-year period during which a policy is implemented. The vertical axis represents changes in state variables compared to the state at the end of the first 20-year period. Each level represents a 10% change along each dimension. Data associated with this figure can be found in Appendix A8 through A10.

elements and dynamics of a system, and the appropriate level of details is determined by and should be sufficient for addressing the research question.

All three modeling approaches are useful, and they can complement each other to enhance our understanding of policy effects. Above all, understanding how households make decisions should be an important component for policy analysis and deserve particular attention in future research. Such understanding can help explain correlations found by econometric models and inform general equilibrium and agent-based models. From a complex adaptive system perspective, only if we understand how households make decisions, may we design polices that effectively induce individual decisions to collectively shape the system toward more desired states (Tian, 2011). Rural households with different characteristics situated in different local settings have different responses to the same policy (Tian et al., 2015). Therefore, we should expect different effects of the subsidy policy across locations and among households, which are also demonstrated by our ABM and confirmed by Yi, Sun and Zhou (2015). Future research needs to pay more attention to these differences, because they suggest differentiating policy interventions that are necessary to effectively promote agriculture and rural development.

3.2. Effects of the rental-subsidy policy

The rental-subsidy experiments suggest that different villages respond to varying amounts of subsidy for long-term contracts differently (Fig. 5). In villages with average farmland resources (V2), increasing subsidy size produces noticeably larger improvements in model simulations (Fig. 5a). Increasing subsidy size, however, does very little to further improve the system in villages with poor or rich farmland resources in model simulations (V1 and V3) (Fig. 5a). These experiment results can be explained as follows. In V1, farmland productivity is low, and most farmer households find migratory work more profitable and largely rely on migratory work for their livelihoods. Therefore, providing a small subsidy to households that rent out their land-use rights would improve the economic circumstances of many households, and most farmland would be transferred through long-term contracts with only a small amount of subsidy. In V3, farmland productivity is high, and most households find farming profitable. Therefore, many households would not give up their land-use rights for long terms even given large amounts of subsidy, and the total farmland area transferred through long-term contracts would increase little as subsidy size increases. In V2, farmland productivity is at an intermediate level, and more households would become better off renting out their land-use rights for long terms as subsidy size increases. Therefore, the total farmland area transferred would increase as the subsidy size increases.

The model experiment also suggests that in all villages, total cost increases as subsidy size increases, resulting in decreases in economic efficiency. The modeled economic efficiency of the rental-subsidy policy appears to have a similar non-linear relationship with subsidy size across villages (Fig. 5b). Both measures of economic efficiency drop quickly as subsidy size increases and become flat later in model simulations. Modeled total cost shows a linear relationship with increasing subsidy size, but the relationship has different slopes for different villages (Fig. 5c). Because total cost associated with a subsidy size is essentially determined by the total area transferred through long-term contracts during the second 20-step period, the slopes of these lines can be interpreted as the efficiency of the rental policy in stimulating the land rental market, i.e., the increase in total rental area per extra unit cost in subsidy. The modeled efficiency of the rental-subsidy policy in stimulating the land rental market remains positive in all places, meaning that the more the government spends in subsidy per unit area, the more area will be transferred through long-term contracts. The slope is larger in villages with average farmland resources (V2), indicating that the rental-subsidy policy is likely to be more efficient in stimulating land rental markets in the majority of villages. This is, again, because farmland productivity in V2 is at an intermediate level, and household decisions on renting out land for long terms are therefore sensitive to subsidy size.

According to this model experiment, the rental-subsidy policy has apparent advantages compared to the current policy, regardless of subsidy size. In model simulations, the rental-subsidy policy leads to a significantly larger and considerably larger improvement in total agricultural production in V1 and V2 respectively (Fig. 5b). The largest improvement of agricultural production in V1 can be explained as combined effects of improvements in extent and intensity of land use and scales of farming operations (Fig.5a). The agricultural production improvement in V2 results from improvements in intensity of land use and scales of farming operations (Fig.5a). With about 100% of its farmland already cultivated currently in V2, there is no room to improve the extent of farmland utilization. The agricultural production improvement in V3 is small and results from small improvements in farming scales, since farmland in V3 is already fully utilized in both extent and intensity (Fig. 5a). Across villages, the rental-subsidy policy increases the scale of farming, though to different degrees (Fig. 5a). It slightly increases total income across villages according to model simulations, more noticeably in villages with average farmland resources (Fig. 5a). In villages with average to rich farmland resources (as in V2 and V3), the rental-subsidy policy is more efficient in promoting both agricultural production and income across the range of subsidy sizes than the current policy (Fig. 5b). In villages with poor farmland resources (as in V1), the rental-subsidy policy is more efficient in promoting rural income across the range of subsidy sizes than the current policy (Fig. 5b).

According to this model experiment, if the government uses the same amount of money to subsidize long-term renters as it is spending on rice cultivation subsidies in each village, it can achieve better effects in most measures across the board (Table 8; Fig. 5). The only disadvantage of the rental-subsidy policy is likely to be in changing farmland cultivation rates. The rental-subsidy policy slightly decreases the percentage of cultivated area in V2 and V3 and improves farmland cultivation rates in V1 to a degree that is slightly lower than the current policy in model simulations. But the increase in farmland cultivation rates under the current policy only translates into a similar degree of increase in rice production and even a small decrease in total income in V1 and V2 in model simulations.

The rental-subsidy policy is more equitable than the current policy. In villages with poor farmland resources, because land rental prices are relatively low, farmer households that intend to specialize in agriculture can rent in large areas at relatively low cost. This compensates for the inherent disadvantage of having poor natural resources. Additionally, most farmer households in villages with poor farmland resources rely largely on migratory work for their livelihoods. If they receive subsidies for long-term contracts, they will be more willing to sign such contracts, and this makes it easier for those households that intend to specialize in agriculture to acquire large farmland areas. The subsidies the renters receive can help improve their urban livelihoods. Thus every rural household in such villages, which tend to be economically less developed than other rural areas, can improve its situation under the rental-subsidy policy.

According to the simulations, rice production under the rental-subsidy policy goes up more levels than the current policy, indicating a potential to grow further, particularly in villages with poor to average farmland resources (Fig. 6). The continued growth in rice production results from increasing intensity of farmland utilization and increasing farming scales. But villages rich in farmland resources do not show a potential for further growth under the rental-subsidy policy in model simulations, similar to the current policy.

According to the simulations, the rental-subsidy policy produces small effects on increasing rural household income across villages. The largest modeled increase in income is below 10% and is present in villages with average farmland resources (Fig. 5a).

The variations of major outcome variables between model runs are reasonably small for most villages, suggesting a reasonable level of certainty in outcomes from the rental-subsidy policy (Fig. 7). The variations in the outcome variables between model runs are smaller, in general, in villages with average farmland resources (V2), and they also show a general trend of decline with increasing subsidy sizes. Therefore, in the majority of villages, the rental-subsidy policy is expected not only to be more efficient in stimulating land rental markets, but also to generate more certain outcomes. Furthermore, the outcomes are expected to be more certain as subsidy size increases. The variations of the outcome variables between model runs appear, in general, to be insensitive to changes in subsidy size in villages with poor farmland resources (V1). Therefore, in such locations, the rental-subsidy policy is expected to produce large improvements in the agricultural system, but the improvements are not expected to change much as subsidy size increases, and neither are the uncertainty of the outcomes. Noticeably large coefficients of variation are found in villages with rich farmland resources (V3), but the rental-subsidy policy is not expected to improve the state of the system much in such villages anyway, which is a limitation of the rental-subsidy policy.

3.3. Robustness analysis

Land rental relationships in rural China often take place between relatives and do not involve payments (Gao et al., 2012; Ma et al., 2015). There are also variations in the implementation of the grain subsidy policy, and in some regions, grain subsidies are given based on historical grain production or contracted land areas instead of actual planted areas (Heerink, Kuiper, and Shi, 2006; Gale, 2013; Huang, Wang, and Rozelle, 2013; Yi et al., 2015). To test how rental contracts between relatives affect our inferences on policy effects, we added a variable in the model, Pct Contracts without Payment, which represents percentage of household agents that go out to rent in farmland and do not pay for rental farmland. We explored its potential range from 0% to 100% with an increment of 10%. To examine how specific implementations of the grain subsidy policy affect our inferences, we implemented an alternative scenario in the model under which grain subsidies are given based on contracted farmland areas and therefore do not affect planting decisions of farmers. The model experiments show that when grain subsidies are given based on contracted areas, the limited effects of the grain subsidy policy on increasing rice production are further reduced as expected, with a small increase in total income and income efficiency because household agents allocate more labor to nonfarm work and earn more income from nonfarm work (Appendix A11–A13).

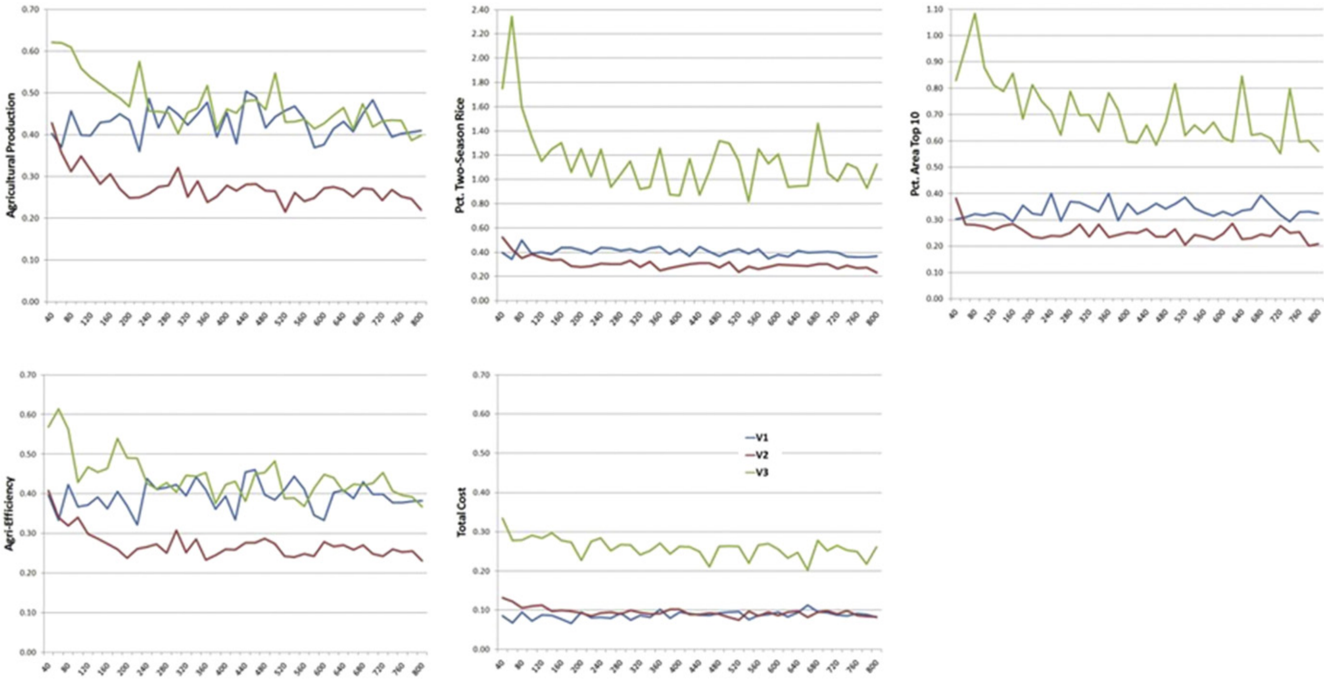

Fig. 7. Variations of major outcome variables between model runs (measured by coefficient of variation). Data associated with this figure can be found in Appendix-A7.

Our earlier model experiments show that the largest positive effect of the grain subsidy policy is increasing land-use extent and consequently rice production to some degree in the farmland-poor village (V1), and the rental subsidy policy is most effective in increasing rice production in villages that have poor and average farmland resources (V1 and V2) due to increased land-use intensity. While slightly reducing the limited effects of the grain subsidy policy, farmland exchanges between relatives can introduce uncertainty to the outcomes of the rental subsidy policy and reduce its effects in some measures (Appendix A11–A16). More specifically, as Pct Contracts without Payment increases from 0% to 100%, the increase in percentage of cultivated area decreases from 13.27% to 11.38% and the increase rate of rice production decreases from 14.50% to 10.04% in V1 under the current grain subsidy policy based on actual planted areas (Appendix A11). As Pct Contracts without Payment increases from 0% to 100%, there is no obvious trend of changes in increase in percentage of two-season rice, increase rate of rice production, and agri-efficiency across the range of rental subsidy sizes in V1 (Appendix A14). As Pct Contracts without Payment increases from 0% to 100%, increase in percentage of two-season rice, increase rate of rice production, and agri-efficiency decrease across the range of rental subsidy sizes in V2 (Appendix A15). With a rental subsidy of 120 YUAN per mu, which likely results in total subsidies similar to the current grain subsidy policy in V2, these measures decrease from 23.04% to 11.48%, 24.57% to 14.40%, and 1.43 YUAN per mu to 0.78 YUAN per mu respectively. Therefore, the robustness analysis enhances our understanding of policy effects but does not alter our major inferences that grain subsidies have very limited effects on promoting rural development, and rental subsidies are likely to produce larger effects than grain subsidies.

3.4. Broader policy implications

In addition to demonstrating some apparent advantages of the rental-subsidy policy over the current policy of subsidizing grain producers, our model experiments generated several insights that have broader policy implications.

That both subsidy policies show limited effects on increasing rural income indicate that rural development in China will continue to depend on the growth in the industrial sector, the engine of overall economic growth, in agreement with the consensus shared by Chinese scholars (Huang and Peng, 2007). Though China's expanding supports for agriculture since 2008 have contributed to a recent increase in farmer income (at an increasing cost) (Gale, 2013), the rural-urban income gap is still large (NSBC, 2013), and urbanization will necessarily continue to play an important role in significantly reducing this gap, because there is a limit on the degree to which agriculture can increase rural income due to limited farmland and large rural population in China. For urbanization to best benefit rural households, policies and programs need to synergistically foster healthy development dynamics and simultaneous growth of the industrial sector and the rural sector so that all rural households can build robust livelihoods and increase income through different paths (Tian, 2011; Tian, Guo and Zheng, 2016). While continuing to promote growth of the industrial sector to facilitate rural labor transfer and increase migratory work wages and implementing appropriate migration policies to make those rural households that prosper in cities actually settle in cities, in the agricultural sector, land policies need to facilitate larger-scale farming operations in accord with the urban sector growth. Because large cities have limited ability to absorb rural population and face their own environmental and administrative issues, policies may promote further development of small and medium sized cities and encourage rural households to settle in nearby urban areas, which will also help reduce migration cost and ease their adjustment to urban life. The impact of agricultural subsidies on rural income under both policy scenarios is likely underestimated in our study for reasons we discuss in the section on model limitations.

That villages with average farmland resources are sensitive to subsidy size in the model and that the largest modeled efficiency of the rental-subsidy policy in stimulating the land rental market is found in villages with average farmland resources present an opportunity: the government could use subsidy size as an instrument to effectively stimulate land rental markets in the majority of villages. Land consolidation through rental markets should not aim mainly to achieve highest land use efficiency, but more to benefit farmer households (Chen et al., 2014). As the industrial sector grows, more rural labor can be employed in the urban sector, greater concentration of farmland can increase agricultural productivity without harming any farmers but benefiting those who stay in the rural area. Increasing subsidy to renters can then facilitate the labor transfer process and keep the development of the agricultural sector in concert with the urban sector growth, helping all rural households to increase income regardless of their livelihood types: urban work oriented livelihoods, agricultural work oriented livelihoods, or urban and agricultural work mixed livelihoods.

The government can choose rental subsidy size to deliberately address the inherent inequality in natural resources between places. There is also room for the government to use rental subsidy size as an instrument to promote rural development and address the issue of inequality simultaneously. The modeled responses to varying subsidy sizes in different villages suggest that the rental-subsidy policy can play different, effective roles in different villages. The most effective roles of the rental-subsidy policy are (i) to compensate for poor natural endowments and improve the agricultural system in villages with poor farmland resources; (ii) to use subsidy size as an instrument to stimulate land rental markets and increase agricultural production and rural income through larger scales of farming operations in villages with average farmland resources; and (iii) to create a social effect by showing that the government supports rural households that rent out their land-use rights for long terms in villages with rich farmland resources.

We looked at three scenarios to show how the government can allocate the subsidy budget differently to reflect these diverse policy roles (Table 9). To promote equality, the government can give at least the same amount of total subsidy to each village (Scenario A in Table 9). To further address natural resource inequity, the government can allocate the total subsidy such that villages receive an amount of subsidy inversely proportional to their farmland resources (Scenario C in Table 9). The government can also apply the same amount of subsidy per unit area in all places (Scenario B in Table 9). We chose 240 YUAN per mu for long-term renters in Scenario B because it has several interesting properties according to model simulations. In V2, the increasing effects of the rental-subsidy policy begin to level off beginning at 240 YUAN (Fig. 5a). Because the majority of villages have about average farmland resources, we expect this subsidy amount will produce larger overall economic effects. 240 YUAN per mu appears to be a reasonable amount considering that the average net income from growing one-season rice is about 600 YUAN per mu and the rental price is about 150 YUAN per mu in the village with average farmland resources. And all three villages achieve a similar efficiency in increasing agricultural production with 240 YUAN per mu. Interactive model runs also demonstrate that the state variables exhibit similar patterns of change in the second period, even with different amounts of subsidy provided to long-term renters.

3.5. Limitations of the model

A major limitation of the study is that our model underestimates rural income, because it only examines direct payments to farmer households based on planted areas with grain and does not include other types of subsidies, such as machine subsidies and price supports. Also, the model only includes major economic activities of rice cultivation and migratory work and excludes other activities, such as animal husbandry, cotton and vegetable production, and business. Several studies show that most farmer households in rural China are liquidity-constrained (Li and Zhu, 2010; Turvey, et al., 2011; Li et al., 2013). Agricultural subsidies and nonfarm income are expected to relieve these liquidity constraints and thereby to affect land sizes, input use, crop choices, migration decisions, nonfarm investments and other household decisions (Heerink, et al., 2006; Meng, 2012; Yi, Sun and Zhou, 2015). However, we do not expect that the relaxation of credit constraints has significant effects on improving income for the majority of households. Our empirical study suggests that an average Chinese farmer household faces a range of constraints (Tian, 2011; Tian, Guo and Zheng, 2016). The small scale of agricultural production and unwillingness/inability to take risk are among the most important constraints that limit its crop choices, higher-return activities, and investments. Many household members work in cities far away from home and cannot work on agriculture at the same time even if their nonfarm income allows them to increase farm sizes. Influenced by nonfarm income, farmer households value leisure more than before and give up activities that used to be widely practiced, such as pig raising. Those households that have a diverse and higher-return livelihood profile are few in number, and subsidies are not a contributor to their livelihood choices.

The effects of the rental-subsidy policy may be underestimated, because as farming scale increases and as farmer households are assured of their long-term rights to use land, new land-use practices that are more suitable for the biophysical characteristics of farmland will become feasible and can generate higher economic returns. This should further improve the system, especially in places with poor farmland resources.

The decision making of household agents in the model is a simplified one and does not consider leisure, risk preference and other objectives. And the way farmer households decide to rent in/out land-use rights for the long term is not based on empirical data. Future work will include interviewing farmer households to investigate the conditions under which they are willing to sign long-term contracts.

Our model assumptions can also affect simulation outcomes and the quality of inferences. The assumption that farmers' input use is unaffected by subsidies can be largely justified by our empirical study. Based on our interviews and field observations while staying with farmers in different villages around Poyang Lake, farmers do not seem to have increased input use of fertilizers or pesticides because of grain subsidies. Rice cultivation practices, including the types and amounts of fertilizers and pesticides that are used, are similar among households and across villages. A main difference is that farmers put in more efforts in agriculture in the farmland-rich village than other villages because rice

Table 9
Three scenarios with the rental-subsidy policy.

Aspect	Measures	Similar total cost (Scenario A)			Same subsidy per unit area (Scenario B)			Pro-poor (Scenario C)		
		V1 (240)	V2 (160)	V3 (360)	V1 (240)	V2 (240)	V3 (240)	V1 (360)	V2 (160)	V3 (200)
Changes in the state of the system (%)	Agricultural production	52.15	25.87	3.66	52.15	27.07	3.67	55.36	25.87	3.47
	Total income	1.85	7.48	4.50	1.85	7.83	4.12	1.92	7.48	3.74
	Pct. cultivated area	7.97	−0.44	−0.08	7.97	−0.23	−0.15	8.35	−0.44	−0.01
	Pct. two-season rice	32.22	24.86	0.51	32.22	25.74	0.58	33.74	24.86	0.51
	Pct. area top 10	34.87	42.90	7.19	34.87	42.62	7.32	35.50	42.90	6.67
Economic efficiency	Agri-efficiency	0.67	1.10	0.48	0.67	0.72	0.76	0.46	1.10	0.89
	Income-efficiency	0.40	1.87	1.33	0.40	1.20	1.81	0.26	1.87	2.01
Total cost in each place (YUAN)		1. 1,177,630	2. 1,140,211	3. 1,203,876	4. 1,177,630	1,862,592	748,426	1,804,933	1,140,211	602,486
Total cost in all places (YUAN)	3,561,858 (current policy)	3,521,717			3,788,648			3,547,630		

cultivation generates relatively large return there. After all, the current grain subsidy size is small especially compared to nonfarm income and probably does not provide sufficient incentive for farmers to increase input use. Particularly, under the scenario that grain subsidies are given based on contracted areas, there is no incentive for households to increase input use. Under the rental subsidy policy, large farms may increase input use. However, large farms are also likely to negotiate lower prices for fertilizers and pesticides, and the yield functions in the model are conservative. Therefore, the assumption of farmers' input use is unaffected by subsidies is unlikely to significantly change our major inferences on policy effects.

Though most of the literature on farm size and productivity focuses on an "inverse" relationship between farm size and productivity (Eastwood, Lipton and Newell, 2010), our assumption that rice yields increase as the area of farmland managed increases can be largely justified by increased efforts, possible improvements in irrigation conditions, machinery usage, and other innovations in the current Chinese context that farmland is highly fragmented and the scale of farming is very small. Furthermore, our model simulates family farms that do not hire labor, and consequently the costs involved in monitoring labor, a major contributor to the inverse relationship, are irrelevant. That farmer household agents do not hire labor in the model is our deliberate choice. When farming operations get bigger, there will be incentive to hire in labor, and it is necessary to use hired labor during some periods (for example, during rice planting season). If the model were to allow household agents to hire in labor, even larger scale of farming operations would be possible, which would lead to a greater inequity between households. Given the large rural population in China, extreme farmland concentration is not desirable at the current stage of development, and the government can place some regulations to guide healthy labor hiring practices so that the degree of farmland concentration increases in accord with the urban sector growth to benefit all farmer households.

We acknowledge that things are always more complex on the ground than any model can represent, and the model does not address issues regarding policy implementation. Revisiting the study site in winter 2014, we found that some legal firms are now dealing with formal farmland lease contracts. The rental subsidy could be administered through these firms. We also noticed that the Chinese government has recently increased special supports to large farms in various forms including cash awards and subsidies or loans for construction of farm facilities, such as grain drying floors etc. This instrument appears effective at promoting large scales of farming operations, though systematic assessments are still needed. Its implementation is relatively easy, because the supports are targeted at a few. But it increases inequality.

4. Conclusions

We use an empirically grounded agent-based model to explore the potential effects of subsidy policies on rural development in the Poyang Lake Region of China. The modeling experiments provide an expanded understanding of multiple effects of an alternative policy that subsidizes households that rent out their land use rights under formal contracts for long terms in comparison with the current policy of subsidizing rice producers. The current grain subsidy policy overall has limited effects on promoting rural development. It further increases inequality, because farmland-rich places receive much more subsidy than other places. It can only produce immediate and short-term effects. Subsidizing long-term renters appears to have apparent advantages in promoting rural development over the current policy. It is expected to move the agricultural system to a more desired state with less cost in most places. It is more equitable by making every household in farmland-poor places better off and can be used to further address farmland inequality between places. It is also expected to create the potential for continuous improvement in the agricultural system. The rental-subsidy policy can most effectively stimulate land rental markets in places with average farmland resources. However, such a policy is unlikely to improve the agricultural system in places with rich farmland resources. Both polices show limited effects in increasing rural income, suggesting rural development in China is tightly linked to and will continue to depend on the growth in the industrial sector.

Our study also demonstrates that agent-based modeling can be a valuable tool for examining the impacts of both local processes and broader development contexts on individual farming systems with heterogeneous characteristics. It can help improve our understanding of different policy responses across local settings and provide rich, useful insights into how policy interventions may play different roles in different places to effectively promote social and economic development.

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Appendix A. Supplementary data

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