From Vulnerability to Sustainability: Rural Development in the Poyang Lake Region of China amid Institutional Changes and Flood Hazards

by

Qing Tian

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Doctoral Committee:
Professor Daniel Brown, Chair
Professor Stephen Salant
Associate Professor Maria Lemos
Associate Research Scientist Rick Riolo

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ABSTRACT

With till-low development levels and relatively high risks from climatic impacts, the less developed world faces a greater challenge for future development than developed economies. Applying the science of complexity to study human-environment systems (CHES) and integrating ideas from climate change research into a larger framework of sustainability, this dissertation attempts to operationalize the concept of sustainability and provide analyses that are useful for achieving sustainability in less developed places vulnerable to climatic hazards.

In the first chapter, I present a new framework for studying sustainability of CHES. In the framework, I use *well-being* and *resilience* to characterize sustainability. With chapters 2 through 5, I present a case study in the Poyang Lake Region of China (PLR) using the new framework. The study aims to understand how the complex interactions between individual households and the social and environmental setting shape the well-being of rural households. It is also intended to generate insights into (i) how polices can effectively promote social and economic development and mitigate flood impacts, and (ii) how rural households can increase their overall well-being. In addition, it demonstrates the three analyses that support the three steps toward sustainability under the new framework.

Following an introduction to the study area and policy context in the second chapter, chapter 3 presents a regional-scale assessment of well-being combining remote sensing, GIS, and socio-economic data. Chapter 4 presents an in-depth analysis of underlying causes of well-being based on surveys and interviews. Chapter 5 presents an analysis of rural development policies using an agent-based model. In the final chapter, I reflect on this research and discuss future work that expands this research to more general analyses of sustainability at local and global levels.

My findings focus on interactions between individual households and their social and environmental settings, which explain rural development at the aggregate level, and variations in well-being between rural households and across places. Specifically, I found that constraints associated with rural and urban development dynamics at the national level, and issues around land-use rights limit the choices and outcomes of rural household livelihoods. Through modeling, I showed that an alternative land policy may help loosen these constraints and promote rural development.

Chapter I

A Framework for Studying Sustainability in Less Developed Places amid Climatic Hazards

Introduction

Sustainability has become a major issue for humanity in the 21st century (Kates et al. 2001; Clark and Dickson 2003; Clark 2007; Kates and Dasgupta 2007; Ostrom et al. 2007; Perrings 2007; Turner et al. 2007; Moran 2011), but the concept of sustainability remains vague (Kajikawa 2008; Kim and Oki 2011), and how to achieve sustainability a significant challenge (Levin and Clark 2010). The perspective of coupled human-environment systems (CHES) is likely to bring different disciplines together and has the potential to integrate the diverse understandings of sustainability. Because technologies alone cannot solve all environmental problems, an alternative approach that looks at human actions, biophysical processes, and interactions between the human system and the natural system is also necessary to understand the dynamics of CHES and generate insights into long-term solutions.

Attaining sustainability becomes even more difficult because of the impacts of climate change (IPCC 2001; IPCC 2007), and human adaptation to climate change is widely considered necessary (Parry et al. 1998; Adger et al. 2003; Dixon et al. 2003; Pielke et al 2007; Lemos et al. 2007; Agrawal 2008). But the impacts of climate change will not be distributed equally, with the less developed world suffering higher risks (Kates 2000; Adger et al. 2003; Adger et al. 2006). The impacts of climate change are and will be experienced locally, and those impacts will vary from place to place. In any given place, there are multiple factors and constraints that affect development. Especially in less developed areas, there are usually issues that are more pressing than climate change. And in many places where climate change has or will have a significant impact, climate variability already exerts some influence on the system. Therefore, it will be more fruitful to view climate as one of the many factors in and constraints on development, rather than singling it out when examining current development patterns and making future development plans (Wilbanks and Kates 2010).

With still-low development levels and higher risks to climatic impacts, the less developed world faces more challenges for future development than developed economies. By integrating useful ideas from climate change research into a larger framework of sustainability, this dissertation attempts to concretize and operationalize the concept of sustainability from the perspective of CHES guided by the science of complexity, as well as provide analyses that are useful for achieving sustainability *in less developed places amid climatic hazards*. The framework is also intended to support development policy-making in the field by providing a clear understanding of the state of CHES, analyzing the dynamics of such systems, and exploring potential outcomes of policy interventions.

The science of complexity and sustainability of CHES

CHESs are complex adaptive systems (CAS) (Levin 1999; Gunderson and Holling 2002; Turner et al. 2003; Liu et al. 2007; Ostrom 2009). In CAS, a network of diverse autonomous agents act and interact with each other and with the environment, and, as a result, coherent behaviors, macro patterns, or global properties of the system emerge in a bottom-up fashion (Holland 1995; Holland 1998). The evolution of CAS is path-dependent, meaning that the later state of a system depends on its initial and previous states, and the state space of such systems is vast. There are "tipping points" where the system will experience a sudden state transition. There are also “lever points” that can produce large changes with a small amount of intervention.

In systems dynamics, which is an earlier paradigm of complexity science than CAS, the state of a complex system is represented by multiple variables. Researchers use interconnected changes of these system-level variables to explain the dynamics of the system (Luenberger 1979). By looking one level down at agents to explain the dynamics of complex systems, the newer paradigm of complexity science advances our understandings of CAS. Using multiple variables to represent the state of a CHES and seeking to explain how the agents in the system act and interact driving state change bring a promise for understanding and studying sustainability.

When we look at CHES as CAS, we can understand sustainability as a global property of CHES, emerging from the actions and interactions of multiple human players within the large social-economical-political setting, the biophysical processes of the environment, and the interactions between the human system and the natural system (Figure 1–1). Sustainability is essentially about the well-being of CHES over the long term because high levels of human well-being cannot be attained or maintained without the support of the natural system. And we can use multiple variables to measure various aspects of human and environmental well-being.

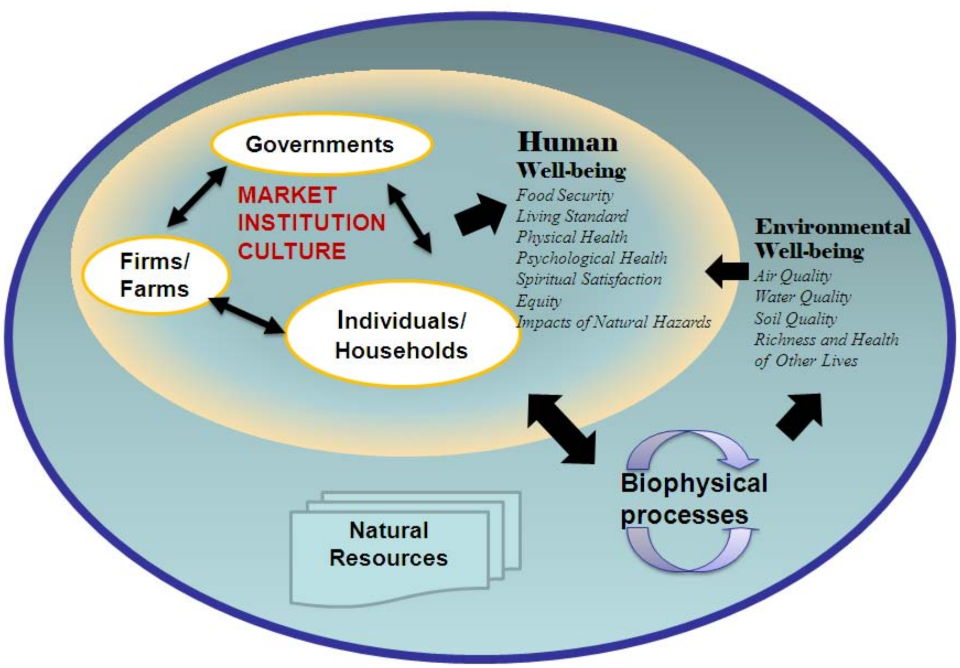

Figure 1–1 Sustainability of coupled human-environment systems.

In any CHES, there are multiple issues that can affect human and environmental well-being, and therefore, sustainability can be characterized across multiple dimensions, including natural resources, biodiversity, pollution, climate change/variability, etc. But in a given system, one or some dimensions are often more important than the others. We may begin with the most important (or the most concerned) dimensions, and then include other dimensions gradually to understand sustainability of the system in its full range.

The definition of sustainability and the framework I propose in the next section is limited to *the dimension of climate change/variability* and is intended to study sustainable development *in less-developed places*. Because humans are the only agents in CHES that can take action deliberately to change the state of the system, this framework focuses on analyzing the social system, while accounting for relevant information about the natural system. I will discuss how to extend this framework to more general analyses of sustainability at local and global levels in the final chapter of this dissertation.

A framework for understanding sustainability in less-developed places amid climatic hazards

The framework uses two concepts to characterize sustainability: *well-being* and *resilience*. Well-being describes the state of a CHES at one point in time, while resilience describes the state change of the system.

The well-being of a CHES is further defined within a three-dimensional space: (1) *exposure* of the human system, which characterizes the nature and degree to which the human system is exposed to climatic variations or extremes and is determined by the natural environment, (2) *development level*, which includes various aspects of human development, and (3) *sensitivity*[1] of human development, which reflects how human development is affected by climatic variations or extremes.

A system is defined as *resilient* if it does not experience a sudden transition between critical states of well-being in the face of social or environmental shocks.

A system is defined as *sustainable* if its development has reached a certain level, and it is resilient.

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[1] Please note that the definitions of exposure and sensitivity are not the same as the IPCC definitions. In the IPCC conceptual framework for vulnerability assessment (Houghton et al. 2001; McCarthy et al. 2001; Fussel and Klein 2006), climate variability and extremes are treated as external to a system, which can be any social or natural system. Exposure is defined as “the nature and degree to which a system is exposed to significant climatic variations.” Sensitivity is defined as “the degree to which a system is affected by climate-related stimuli.”

The framework is simple. Imagine a system occupies one spot in the 3D space of well-being at any given time. Underneath, humans act and interact with each other and with the natural environment within the large social-economic-political setting, determining where the system is and where it will go. Resilience involves tracing the trajectory of well-being over time (Figure 1–2).

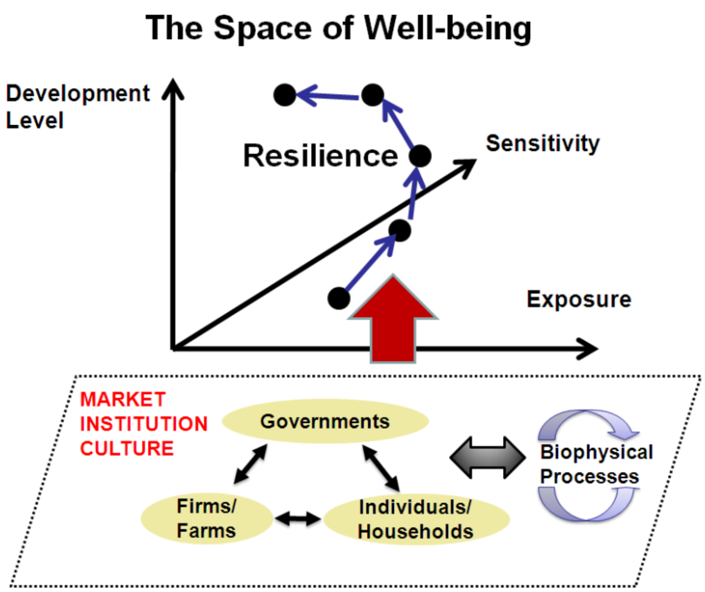


Figure 1–2 A conceptual framework for understanding sustainability in less developed places amid climatic hazards.

Under this conceptual framework, three steps are important for shaping a CHES gradually toward sustainability: (i) figure out where the system is at the present time; (ii) understand how multiple human players act and interact with each other and with the environment under the large social-economic-political setting driving state change; (iii) design policies accordingly and explore the potential effects of designed policies. These steps need to be repeated over time to reflect constant social and environmental changes (Sustainability is a dynamic process, and there are no fixed solutions to it.). The steps can be supported by three kinds of scientific analyses: assessing well-being, analyzing multi-source and multi-level causes of well-being, and exploring future paths of a system.

The social science of climate change

This framework can be viewed as a synthesis of ideas and thoughts from the social sciences of climate change and development. Below, I explain why I chose some concepts over others, and how the analysis of vulnerability and adaptation can be integrated into this sustainability framework.

The concepts of exposure and sensitivity are important because they allow us to understand the nature and impacts of climate change/variability and capture the essence of vulnerability. As defined in this framework, exposure and sensitivity offer objective measures of the biophysical environment and the outcome of interactions between the human system and the environment with respect to climatic variations/extremes. As long as the human system is exposed and human development is sensitive to climatic variations/extremes to some degree, people are susceptible to harm when hazardous climate events manifest, and hence, are vulnerable.

Exposure also serves as a reference point to sensitivity and reveals if people are doing things that exacerbate or ameliorate their risks. Together with development level, they provide a comprehensive view of human well-being and the state of the environment with respect to climatic variations/extremes, reveal how development can be affected by climatic variations/extremes, and suggest where people should make adjustments or what people may do to achieve sustainability in the context of climate change/variability (Table 1–1).

Table 1–1 System states and possible implications

Development	Exposure	Sensitivity	Possible Implication
High	Low	Low	Desired state.
High	Low	High	Doing things that exacerbate risks - need to locate the sensitive part of development and make appropriate adjustments.
High	High	Low	Good - doing things that ameliorate risks.
High	High	High	Serious problem - may need to seek both engineering works and “soft” means to reduce sensitivity.
Low	Low	Low	Key issue is development, but need to make sure not to do things that exacerbate risk.
Low	Low	High	Key issue is development, but need to reduce sensitivity at the same time.
Low	High	Low	Key issue is development, but need to pay close attention to sensitivity and may need engineering works

			to keep sensitivity low.
Low	High	High	Might consider migration away as an ultimate solution.

The concept of social vulnerability, with its roots in political-ecology/political-economy, is essentially about the well-being of people. In the literature, social vulnerability is usually measured by combining some socio-economic variables, such as socio-economic status, access to resources, age and gender, the degree of urbanization, occupations, infrastructure, education and social capital (Cutter et al. 2003; Dwyer et al. 2004; Vincent 2004; Rygel et al. 2006). But exactly how these variables determine vulnerability is not fully understood, and their effects are likely to vary in different contexts. What is actually measured is people's well-being.

Some researchers, particularly those who have work experience in less developed countries or with socially and economically disadvantaged groups of people (social vulnerability is almost always associated with such groups), have realized that the central issue of social vulnerability is development, and the well-being of people is the real concern (Ribot et al. 1996).

The vulnerability analysis that seeks to understand how social and political processes affect the vulnerability of people (Sen 1981; Hewitt 1983; Dreze and Sen 1990; Swift 1989; Watts and Bohle 1993; Blaikie et al. 1994; Ribot 2009) is important and can be expanded to analyze the multi-source and multi-level causes of well-being under the new framework.

The concept of resilience (Holling 1973; Carpenter et al. 2001; Folke et al. 2002; Berkes et al. 2003; Folke 2006; Walker and Salt 2006), which generally refers to the ability of a system to maintain its basic function and structure in the face of shocks, is useful because it represents one part of the sustainability picture, i.e., the state change of a system. However, because many CHESs are now in a state of *undesirable* resilience, i.e., human development level is low and/or the environment is in bad condition (this is precisely why sustainability is an urgent issue), our analyses may focus more on how to break the current undesirable resilience and create a system transit to more desirable states.

The usefulness of the concept also depends on our ability to operationalize it. There are multiple lines of resilience thinking in the literature. A ball-in-a-basin model is used to illustrate the potential states, transitions, and adaptive cycles as a metaphor to understand the evolution of a system (Walker and Salt 2006). My intent here is not to incorporate all the meanings of resilience but to define it in a way that is useful for the study of sustainability by making it more concrete. When we quantify well-being using multiple variables, we can use thresholds of these variables to partition the space of well-being into discrete states and define critical states. We can then combine the tools from the two paradigms of complexity science (i.e., systems dynamics and complex adaptive systems) to trace the trajectory of well-being and deploy the concept of resilience.

When we look at climate as one of the many factors and constraints that affect human well-being in a place, adaptation to climate change/variability naturally becomes part of the sustainability agenda. Sensitivity of human development in a way provides a measure of the outcome of human adaptation: if over time people make development less sensitive to climate variations/extremes, they are adaptive and adapt in the *right* direction. The three steps toward sustainability within this framework, which I outlined in the previous section, are also important for *progressively* adapting to social and environmental changes and enhancing adaptive capacity.

Implementations

Assessing well-being

Assessments can be carried out for a given time and at different scales. In particular, a regional assessment of well-being is useful for policy makers to understand the variations in development, exposure, and sensitivity across places in the region, to design policies accordingly to target different problems in different places, and to identify hot spots for further investigation. Each dimension of well-being can be represented by multiple variables to examine different aspects of human development in relation to climatic variations/extremes.

Representing development level, life expectancy, literacy, and income, which were used by the United Nations Development Program (1990; 2007; 2008) in the human development index, are good common indicators to begin with. Other variables could be included to have a more comprehensive view of human development or to reflect specific concerns in a place. The World Bank (2009) has listed more than 800 indicators for various aspects of development. But we need to be aware that more measures are not necessarily better than fewer measures. Including many relevant but unimportant variables is likely to mislead or overwhelm assessment users and prevent them from seeing the essential parts of the picture. An assessment can generate the most insightful information if it captures the system's key elements using the fewest variables. We may pay attention to how the different aspects of development are related to better understand the multiple facets of human development and how economic advancement affects overall human well-being.

Exposure and sensitivity measures are specific to places and climate events. Area extent, speed of onset, spatial distribution, temporal spacing, duration, and frequency are commonly used in natural hazard research (Burton et al. 1978; Burton et al. 1993) to describe the nature and magnitude of extreme events. They are, therefore, appropriate for measuring exposure of the human system to climatic variations/extremes. Two types of outcomes are essential to consider in measuring sensitivity: *human lives* and *economic activities*. In different places, major economic activities may be different, but in each place, *land-use* patterns are direct manifestations of human activities that interact with the environment. They indicate how economic activities can be affected by climatic variations/ extremes, and therefore, are good common measures of sensitivity. The distribution of important public facilities and existing engineering works also affect sensitivity and need to be considered.

Exposure and sensitivity are often spatially varied in a region. To characterize the spatial variations of exposure, *risk zones* can be defined and mapped using a theoretical approach based on the nature of the risk or generated empirically using historical data on extreme climate events. Land-use patterns can be interpreted from remote sensing images, and then used with other GIS data (such as road networks, crucial facility locations, and population distribution) to calculate their quantities and proportions in different risk zones to characterize the variations of sensitivity.

Assessments can be performed, first using each variable, and then combined to produce an assessment of well-being in one dimension. The assessments using individual variables provide richer information than a composite index-based assessment. For instance, high incomes may not be correlated with other aspects of development, and we can, therefore, identify different problems in different places. The assessments in each dimension can be further combined to produce an assessment of overall well-being in the format of maps, which are easily accessible to policy makers.

Analyzing multi-source and multi-level causes of well-being

An analysis of the causal structure of well-being provides important insights about how policies can effectively improve processes and eliminate constraints at the system level, and what people could do better at the micro level to increase overall well-being. Such an analysis can also shed light on the fundamental processes that shape human and environmental well-being of a CHES.

To understand the causal structure of well-being, we must integrate social, economic, institutional and environmental perspectives. We need to consider the characteristics of individuals, households, and firms, look at social-economic-political settings, and include factors from the biophysical environment, including climate. We need to investigate the *decision-making processes* of individuals, households, and firms because their decisions and actions collectively drive the state change of the system. And through their decisions and actions, institutional and cultural settings and the biophysical environment play their roles in shaping the state of the system. By understanding the decision-making processes of individuals, households, and firms, we may design policies that *induce* individual behaviors that collectively lead to desired outcomes. We need to investigate the interactions (interactions between individuals, households, and firms; interactions between these entities and large social-economic-political settings; and interactions between human activities and the environment) because it is these interactions that often lead to *surprising* outcomes in a complex system.

To analyze the causal structure of well-being, we can combine quantitative and qualitative approaches. We can analyze social surveys with statistical analyses to discover *what* social, economic, institutional, and environmental factors and forces are at work. We can use open-ended interviews and observations to investigate the decision-making processes and reveal *how* these factors and forces interact with each other to affect the decisions and actions of individuals, households, and firms, and shape the well-being of the system. While statistical analyses are good for finding patterns with large datasets, qualitative approaches allow us to develop in-depth understandings about underlying processes and look at social factors that are hard to quantify and, therefore, often omitted in quantitative analyses. Quantitative and qualitative approaches can also complement each other to confirm our findings.

Exploring future paths of the system

To effectively shape a system toward more desired states, we need to *explore* the potential paths of the system under different scenarios of social and environmental changes. If we can tell where the system will go with certain policy interventions, we can have more confidence in the policies we choose to implement. If we find "lever points," our policy interventions can induce a system out of undesirable resilience with less cost. If we can identify conditions that lead to un-sustainability or "tipping points," where the system would transit to an undesired state, we will have a better chance to avoid a disastrous future.

By coupling an agent-based model (ABM) (Epstein and Axtell 1996; Axelrod 1997; Riolo et al. 2001; Bankes 2002; Janssen 2003; Parker et al. 2003; Berger et al. 2006; Brown and Robinson 2006; Farmer and Foley 2009) with network analysis (Wasserman and Faust 1994; Barabási 2002; Buchanan 2002; Skvoretz 2002; Newman et al. 2006) from the science of CAS and mathematic tools (LaSalle and Lefschetz 1961; Martynyuk 1998; Bramson 2009; Bramson 2010) from systems dynamics, we can explore the potential effects of policies, look for "lever points" and "tipping points," and deploy the concept of resilience. In this respect, the model experiments may focus more on how the human agents in a system could act differently in order to shape the system toward sustainability and avoid disastrous future outcomes. ABMs have been increasingly used to study human behaviors and economic and ecological processes, but its exploratory potential needs to be further unlocked to generate *new, useful,* and *convincing* insights about CHES.

By integrating social, economic, institutional, and environmental factors through the decisions and actions of the human agents, and capturing the interactions between the human agents and the environment, ABMs can also help us theoretically understand the fundamental processes underlying sustainability or un-sustainability.

Looking ahead

In the following chapters, I present a study on rural development in China's Poyang Lake Region (PLR) using this framework. PLR is a less developed area in Jiangxi Province. Historically, it has been subjected to flood hazards from the largest fresh water lake in China. Like other rural areas in China, it has been experiencing fast and dramatic social-economic-political changes due to national policy reforms. This study aims to understand how the complex interactions between individual households and the social and environmental setting shape the well-being of rural households. It is also intended to generate insights into (i) how polices can effectively promote social and economic development and mitigate flood impacts at the same time, and (ii) how rural households can increase their overall well-being under social and environmental changes.

In the second chapter, I begin with an introduction to the study area, including basic socio-economic characteristics, agricultural system, natural environment, flood history, and the current engineering works used for mitigating flood impacts. I also describe national policies regarding economic reforms and rural development under which rural households develop and carry out their livelihoods. In addition to flood hazards, farmer households in PLR confront the same challenges for improving living standards as other rural households in China.

In the third chapter, I present a regional assessment of well-being. The assessment was carried out for 298 towns in PLR. I used an innovative approach to map flood-risk zones with a digital elevation model, levee GIS data, and historical data on lake levels. I then combined land-use data interpreted from remote sensing images and population distribution map with the flood-risk zones to derive measures of exposure and sensitivity of existing development to flooding. I used socio-economic data from the census to represent three aspects of development level: health, literacy, and income. The assessment indicates that the overall development in PLR is highly exposed and sensitive to flooding, and there are large variations in development level, exposure, and sensitivity among the 298 towns in PLR. Sensitivity is closely related to exposure with both levels higher closer to the lake. The development levels, however, are more associated with the degree of urbanization of a town and distance to the county capital. The measures of income and education are associated to some degree, but the measure of income is not correlated with the measure of health. I identified several types of towns that deserve particular attention for future development, discussed their different sustainable development pathways, and recommended different policy interventions for each of them.

In the fourth chapter, I present an in-depth analysis of well-being at finer scales and its underlying causes based on household surveys and interviews. The analysis focuses on the livelihoods of rural households and integrates multiple perspectives of social vulnerability analysis, sustainable livelihoods analysis, and development economics. Combining quantitative and qualitative approaches, I examined and explained the variations of development level at three levels (communities, groups, and individual households) and demonstrated how various factors and forces from the human system and the natural environment interact with each other to shape the livelihoods and development level of households through their land-use and livelihood decision-making processes. I found that the livelihoods and the development level of rural households in PLR are largely determined by the characteristics of the household (mainly its human and social capital), influenced by some social and biophysical factors at the community level (leadership, location, and natural resources), and greatly affected by national policies (especially development and land policies) and the process of urbanization at the macro level. Most rural households, constrained by small farmland area, their own education levels and skills, the overall development of the industrial sector, and a large supply of rural labor, have few feasible options and rely on migratory work as their major income source. Thus, they are unable to raise their income to another level. I identified four major livelihood profiles (each of which can lead to a high level of development) and analyzed the characteristics of individual households and external conditions that contribute to the success of these profiles. I further looked at flood impacts on the livelihoods of households and the current agricultural practices. I found that the poor households are most affected by flooding. Places with poor farmland resources, with their agricultural production also highly sensitive to flooding, are doubly disadvantaged in terms of development. I discussed the implications of these findings for government policy making and for the local people in PLR and provided some policy recommendations on rural development.

In the fifth chapter, I present an agent-based model to explore how to better shape the future of rural development (i.e., improve agricultural production and increase the well-being of rural households). The model was built upon insights generated from the analysis of land use (described below) and the analysis of household well-being. I used the model to address the following questions: (a) To what degree are farmer households in PLR constrained by the availability of farmland resources? (b) Is the current land rental market efficient enough to match the demand and supply of land-use rights? (c) How effective is the current policy of subsidizing rice cultivation in promoting agricultural production and increasing rural income? (d) Could an alternative policy that subsidizes long-term land-use-right renters induce the system to a more desired state, and how should policies vary across places? I used survey data from three villages that represent different kinds of farmland endowments in amount and quality as empirical reference to calibrate and validate the model. To assess the constraint of farmland, I compared model outcomes from a hypothetical scenario in which there are unlimited farmland resources, and households can acquire land-use rights at no cost with those from real scenarios in each place. To assess the performance of the land rental market, I examined the overall success rates among attempted trades from model experiments under some realistic levels of effort the household puts into finding a trading partner in each place. To evaluate/explore the effects of policies, I examined (i) changes in the state of the system (represented by multiple outcome variables), (ii) economic efficiency (measured by increase of total agricultural production and increase of total income per unit cost), (iii) fairness (in the sense that households with poor farmland endowments deserve more compensation), and (iv) trajectory of the system (which reveals the dynamics of the processes and indicates the potential for future growth). The insights generated by the model experiments are as follows. First, limited farmland resources have significantly constrained the livelihoods of farmer households. The low profit from crop cultivation may have contributed to the low effort they put into crop cultivation but is not the fundamental reason for the low effort they put in crop cultivation, which is mostly due to small farmland holdings. Second, the current private market is efficient enough to match the demand and supply of land-use rights. Thus, no other forms of official markets, which would involve more difficulties and efforts in implementation across the large rural China, are needed. The lack of large farming operations in rural areas is not due to the performance of the land rental market but mostly due to the insecurity inherent in short-term contracts, which currently characterizes leases for land-use rights. Third, the current policy of subsidizing rice cultivation may have done little good and some harm for rural development. It is not fair and only has immediate short-term effects. Fourth, subsidizing long-term renters appears to have apparent advantages in promoting rural development: in most places, the subsidy is likely to move the system to a more desired state and more efficiently and create a potential for continuous future growth. It can make every household in farmland-poor places better off. And the subsidy also has an effect in stimulating land rental markets and is expected to be more efficient in doing so in places with average farmland resources. Though it can be less costly than the current policy, the new policy is expected to have little effect on improving the agricultural system in places with rich farmland resources where a different policy is needed. The effect of the new policy in increasing rural income is expected to be small across places. In the process of urbanization, rural development in China is linked to and depends on the growth of the industrial sector. I also discuss how the information generated from the model experiments could be used to choose the subsidy size to promote rural development and address the inequality of natural resources between places.

In the final chapter, I summarize the findings from the entire dissertation research and reflect on the study of CHES as CAS. I also provide an outlook on future research that expands this dissertation research to more general analyses of sustainability of CHES at both local and global levels.

In the Appendix, I present an analysis of the agricultural land-use system in PLR to understand the mechanism underlying spatial patterns and temporal changes in land use. I combined multilevel models based on surveys and qualitative analysis of interviews to demonstrate how various factors and forces at multiple levels from the human system and the environment interact with the characteristics of households to affect their decisions and actions, which collectively shape land use and drive land-use change in PLR. I found that crop choices on individual plots, as part of the overall livelihood strategies of a household, are affected by not only the biophysical properties of farmland, but also the location relative to urban centers and the characteristics of the household, including its demographic structure, social connections and farmland endowment. The spatial patterns of land use in PLR are largely defined by the biophysical environment, shaped by location relative to urban centers, and finely tuned at the micro level by the characteristics of households. Government interventions have also played a role in shaping land-use variations in space, but they have only reinforced the role of the natural environment. In the past, land-use changes in PLR were mostly driven by policy reforms, which have created an increasingly free-market economy, and are now driven by market forces. In the dynamic process of urbanization, policies, development policies in general, and land policies in particular, will continue to play an important role in driving land-use change in rural China through shaping the dynamics of urban and rural development and by defining land-use rights of rural households. The analysis also suggests that farmer households are economic agents, and their livelihood strategies (including land-use decisions) reflect an attempt to increase their economic benefits in a market economy. The elimination of agricultural taxes and the subsidization of grain production prevent farmer households from deserting their farmland, but their effects on increasing grain production and rural income are small. Farmland size is a lever that can be used by government interventions to promote agricultural production and rural income. Policies aimed at rural development should be targeted in ways that are sensitive to variations in environmental and household characteristics. This analysis of land use complements the analysis of household well-being (presented in Chapter IV) in understanding the decision-making process of households. Because it does not fall into the sustainability framework, I present it as an appendix.

This case study in PLR also serves as an example to further illustrate some of the statements I made in the previous sections and to demonstrate the implementations of the sustainability framework.

References

Adger WN, Huq S, Brown K, Conway D, Hulme M (2003) Adaptation to climate change in the developing world. Progress in Development Studies 3:179-195

Adger NW, Paavola J, Huq S, Mace MJ, (eds) (2006) Fairness in Adaptation to Climate Change. Cambridge, MA: MIT Press

Agrawal A (2008) The role of local institutions in adaptation to climate change. In: The Social Dimensions of Climate Change. The World Bank, Washington, DC

Axelrod R (1997) The Complexity of Cooperation: Agent-based Models of Competition and Collaboration. Princeton Univ. Press, Princeton, NJ

Bankes S (2002) Agent-based modeling: A revolution? Proc. Natl. Acad. Sci. USA 99:7296-7303

Barabási A-L (2002) Linked: The New Science of Networks. Perseus Publishing, Cambridge, MA

Bebbington A (1999) Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. World Development 27:2021-44

Berger T, Schreinemachers P, Woelcke J (2006) Multi-agent simulation for the targeting of development policies in less-favored areas. Agricultural Systems 88:28-43

Berkes F, Colding J, Folke C (eds) (2003) Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge Univ. Press, Cambridge

Blaikie P, Cannon T, Davis I, Wisner B (1994) At Risk: Natural Hazards, People's Vulnerability and Disasters. Routledge, London

Bramson AL (2009) Formal measures of dynamical properties: Tipping points. AAAI Technical Report FS-09(3):2-11

Bramson AL (2010) Formal measures of dynamical properties: Robustness and sustainability. AAAI Technical Report FS-10(3):16-25

Brown DG, Robinson DT (2006) Effects of heterogeneity in preferences on an agent-based model of urban sprawl. Ecology and Society 11:46

Buchanan M (2002) Nexus: Small Worlds and the Groundbreaking Science of Networks. W. W. Norton, New York

Burton I, Kates RW, White GE (1978) Environment as Hazard, Oxford Univ. Press, New York

Burton I, Kates RW, White GE (1993) Environment as Hazard, Oxford Univ. Press, New York

Carpenter S, Walker B, Anderies JM, Abel N (2001) From metaphor to measurement: Resilience of what to what? Ecosystems 4:765-781

Clark WC, Dickson NM (2003) Sustainability science: The emerging research program. Proc. Natl. Acad. Sci. USA 100: 8059-8061

Clark WC (2007) Sustainability Science: A room of its own. Proc. Natl. Acad. Sci. USA 104: 1737-1738

Cutter SL, Boruff BJ, Shirley WL (2003) Social vulnerability to environmental hazards. Social Science Quarterly 84:242-261

DFID (1999) Sustainable Livelihoods Guidance Sheets. Available at http://www.eldis.org/

Dixon R, Smith J, Guill S (2003) Life on the edge: Vulnerability and adaptation of African ecosystems to global climate change. Mitigation and Adaptation Strategies for Global Change 8: 93-113

Dreze J, Sen A (eds) (1990) The Political Economy of Hunger. Clarendo, Oxford, UK, pp 50-67

Dwyer A, Zoppou C, Nielsen O, Day S, Roberts S (2004) Quantifying social vulnerability: a methodology for

identifying those at risk to natural hazards. Geoscience Australia. Available at http://www.ga.gov.au

Epstein JM, Axtell R (1996) Growing Artificial Societies: Social Science from the Bottom Up. MIT Press, Cambridge, MA

Farmer, J. D. And Foley, D. (2009) The economy needs agent-based modeling. *Nature* 460: 685-686.

Folke C, et al. (2002) Resilience and sustainable development: Building adaptive capacity in a world of transformations. In Report for the Swedish Environmental Advisory Council, Ministry of the Environment. Available at www.mvb.gov.se

Folke C (2006) Resilience: The emergence of a perspective for social–ecological systems analyses. Global Environmental Change 16:253-267

Fussel HM, Klein RJT (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change 75:301-329

Gunderson LH, Holling CS (eds) (2002) Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, DC

Hewitt K (ed) (1983) Interpretations of Calamity. Allen & Unwin, Boston, MA

Holdren JP (2008) PRESIDENTIAL ADDRESS: Science and technology for sustainable well-Being. Science 25:424-434

Holland JH (1995) Hidden Order: How Adaptation Builds Complexity. Perseus Books, Cambridge, MA

Holland JH (1998) Emergence: From Chaos to Order. Perseus Books, Cambridge, MA

Holling CS (1973) Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4:1-23

Houghton JT, et al. (eds) (2001) Climate Change 2001: The Scientific Basis. Cambridge Univ. Press, Cambridge

IPCC (2001) Climate change 2001: Synthesis report. Cambridge Univ. Press, Cambridge

IPCC (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Available at http://www.ipcc.ch/

Janssen MA (ed) (2003) Complexity and Ecosystem Management: The Theory and Practice of Multi-Agent Systems. Edward Elgar, New York

Kajikawa Y (2008) Research core and framework of sustainability science. Sustain Sci 3:215–239

Kates RW (2000) Cautionary tales: Adaptation and the global poor. Climatic Change 45(1): 5-17

Kates RW, et al. (2001) Environment and development: Sustainability science. Science 292:641–642

Kates RW, Dasgupta P (2007) African poverty: A grand challenge for sustainability science. Proc. Natl. Acad. Sci. USA 104:16747

Kim J, Oki T (2011) Visioneering: an essential framework in sustainability science. Sustain Sci 6:247–251
LaSalle JP, Lefschetz S (1961) Stability by Liapunov's Direct Method with Applications, Academic Press, New York
Lemos MC, Boyd E, Tompkins EL, Osbahr H, Liverman D (2007) Developing adaptation and adapting development. Ecology and Society 12: 26
Levin SA (1999) Fragile Dominion: Complexity and the Commons. Perseus Publishing, Cambridge, MA
Levin SA, Clark WC (2010) Toward a science of sustainability, CID working paper No. 196. Center for International Development, Harvard University, Cambridge, MA
Lim B, Spanger-Siegfried E (eds) (2004) Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures. Cambridge Univ. Press, Cambridge
Liu J, et al. (2007) Complexity of coupled human and natural systems. Science 317:1513-1516
Luenberger DG (1979) Introduction to Dynamic Systems: Theory, Models, and Applications, John Wiley & Sons, New York
Martynyuk AA (1998) Stability by Liapunov's Matrix Function Method with Applications. CRC Press, New York
McCarthy JJ, Canzianni OF, Leary NA, Dokken DJ, White KS (eds) (2001) Climate change 2001: Impacts, Adaptation and Vulnerability. Cambridge Univ. Press, Cambridge
Moran EF (2010) Environmental Social Science: Human-Environmental Interactions and Sustainability. Wiley-Blackwell, UK
Newman MEJ, Barabási A-L, Watts DJ (2006) The Structure and Dynamics of Networks. Princeton Univ. Press, Princeton, NJ
Ostrom E, Janssen MA, Anderies JM (2007) Going beyond panaceas. Proc. Natl. Acad. Sci. USA 104:15176
Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. Science 325:419-422
Parker DC, Manson SM, Janssen MA, Hoffman MJ, Deadman P (2003) Multi-agent systems for the simulation of land-use and land-cover change: A review. Annals of the Association of American Geographers 93:314-37
Parry M, Arnell N, Hulme M, Nicholls R, Livermore M (1998) Adapting to the inevitable. Nature 395:741-742
Perrings C (2007) Going beyond panaceas special feature: Future challenges. Proc. Natl. Acad. Sci. USA 104:15179-15180
Pielke Jr R, Prins G, Rayner S, Sarewitz D (2007) Lifting the taboo on adaptation. Nature, 445:597-598
Polsky C, Neff R, Yarnal B (2007) Building comparable global change vulnerability assessments: The vulnerability scoping diagram. Global Environmental Change 17:472-485
Ribot JC, Najam A, Watson G (1996) Climate variation, vulnerability and sustainable development in the semi-arid tropics. In: Ribot JC, Magalhaes AR, Panagides SS (eds) Climate Variability, Climate Change and Social Vulnerability in the Semi-arid Tropics. Cambridge Univ. Press, Cambridge, pp 13-51

Ribot JC (2009) Vulnerability does not just fall from the sky: Toward multi-scale pro-poor climate policy. In: Mearns R, Norton A (eds) Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World. The World Bank, Washington, DC
Riolo RL, Axelrod R, Cohen MD (2001) Evolution of cooperation without reciprocity. Nature 414:441-3
Rygel L, O'sullivan D, Yarnal B (2006) A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country. Mitigation and Adaptation Strategies for Global Change 11:741-764
Schröter D, Polsky C, Patt AG (2005) Assessing vulnerabilities to the effects of global change: an eight step approach. Mitigation and Adaptation Strategies for Global Change 10:573-96
Sen A (1981) Poverty and Famines: An Essay on Entitlement and Deprivation, Oxford Univ. Press, Oxford
Skvoretz J (2002) Complexity theory and models for social networks. Complexity 8:47-55
Swift J (1989) Why are rural people vulnerable to famine? IDS Bulletin 20:8-15
The World Bank (2009) World Development Indicators. The World Bank, Washington, DC
Turner II BL, et al. (2003) A framework for vulnerability analysis in sustainability science. Proc. Natl. Acad. Sci. USA 100:8074-8079
Turner II BL, Lambin EF, Reenberg A (2007) The emergence of land change science for global environmental change and sustainability. Proc. Natl. Acad. Sci. USA 104:20666
UNDP (1990, 2007, 2008) Human Development Reports. Available at http://hdr.undp.org/en/reports
Vincent K (2004) Creating an index of social vulnerability to climate change for Africa. Working Paper Series at Tyndall Centre for Climate Change Research. Available at http://www.tyndall.ac.uk
Walker B, Salt D (2006) Resilience Thinking: Sustaining Ecosystems and People in a Changing World. Island Press, Washington, DC
Wasserman S, Faust K (1994) Social Network Analysis: Methods and Applications. Cambridge Univ. Press, Cambridge
Watts MJ, Bohle HG (1993) The space of vulnerability: The causal structure of hunger and famine. Progress in Human Geography 17:43-68
Wilbanks TJ and Kates RW (2010) Beyond Adapting to Climate Change: Embedding Adaptation in Responses to Multiple Threats and Stresses. Annals of the American Association of Geographers 100(4):719-728

Chapter II

Study Area and Policy Context

PLR is largely a rural area in Jiangxi Province composed of ten counties and two cities (Nanchang and Jiujiang) with a total area of 20,970km^2 (Figure 2-1). According to the Chinese Census in 2000, the total population in PLR was about 7.7M. Seventy-six percent of the households in PLR, excluding the two cities, were classified as rural. PLR is a major agricultural production base in Jiangxi. According to the *Jiangxi Statistics Year Book 2005*, during 2004, PLR produced 19.08%, 32.47%, and 34.86% of the total grain, cotton, and aquaculture products respectively in Jiangxi. Compared to other areas in Jiangxi, PLR is less economically developed. In 2004, the average farmer per capita income was 2450CNY, 17.03% lower than the average of 2953CNY in Jiangxi (1 US dollar was 8.28 CNY in 2004).

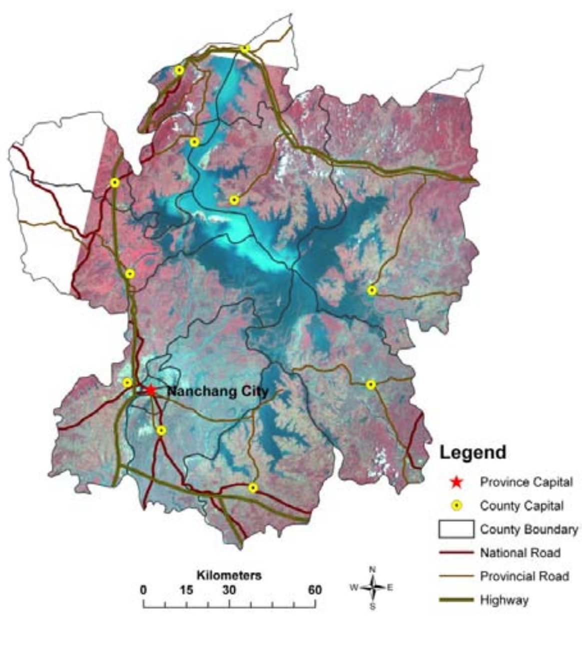


Figure 2-1 The Poyang Lake Region. The image is Landsat TM from July 24, 2004.

The agricultural practices in PLR have been shaped by its physical environment. As a flood plain of Poyang Lake, the terrain in PLR is flat near the lake and gradually rises and becomes hilly further from the lake (Figure 2-2). Rice cultivation has traditionally dominated the economy and is still the major agricultural practice. In PLR, rice can be grown once a year from mid- or late June to early October, which is called one-season rice. Alternately, it can be double-cropped, i.e., after a first crop of early rice is planted in late April and harvested in mid July, a second crop of late rice can be planted in mid- or late July and harvested in late October or early November. However, cotton is usually planted in May and harvested from October until the end of the year. Cotton is an upland crop, and can better tolerate dry conditions than rice. Other agricultural products of the region include rapeseed, sweet potatoes, and peanuts. Rapeseed is usually planted on rice paddies or cotton fields after rice or cotton is harvested and grows throughout the winter season.

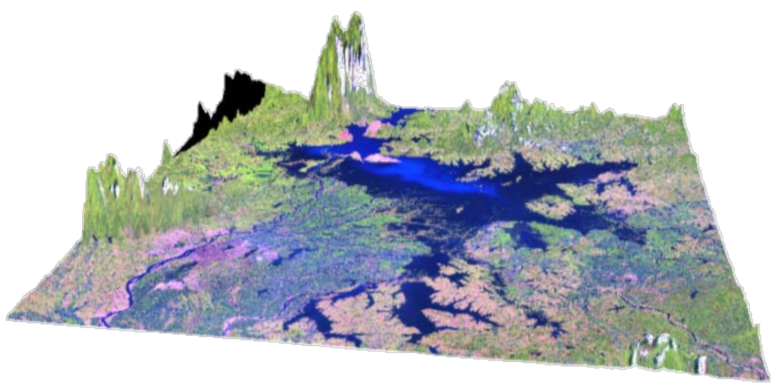


Figure 2-2 The terrain of PLR.

Agricultural production in PLR is subjected to flooding from Poyang Lake, which affects economic development (Zhao and Guo 2001; Zhu et al. 2002; Huang and Dai 2004; Huang et al. 2006; Wang et al. 2006; Chen and Zhao 2007; Ma 2007; Jiang et al. 2008). Poyang Lake is the largest fresh water lake in China. Situated in a structural depression, Poyang Lake collects water from five major rivers in Jiangxi and drains into the Yangtze River at Hukou (about 700km downstream of Three Gorges Dam). Its water level varies considerably throughout the year (Xu et al. 2001; Min 1997a and 1997b). From April to June, the water levels of the five rivers are high due to seasonal rainfalls, and the lake level rises as well. From July to September, the Yangtze River is high due to seasonal rains, and the water can flow back to Poyang Lake, making the lake level rise. Based on lake level records at Hukou between 1950 and 1998, 83.7% of the highest lake levels occurred from July to September, 65.3% of which were recorded in July. Historically, the most severe floods occurred when high water levels in the five rivers and the Yangtze River coincided. Since 1950, the trend has been towards increased rainy-season lake levels and higher severe flood frequency (Figure 2-2; Min 1997a and 1997b; Shankman and Liang 2003). Though no severe floods have occurred in the past decade, according to some local scientists who study the hydrology of Poyang Lake (Min and Liu, Pers. Comm.), concerns remain about flooding because the lake responds to long-term climatic and hydrologic cycles, and may simply be in a low level stage.

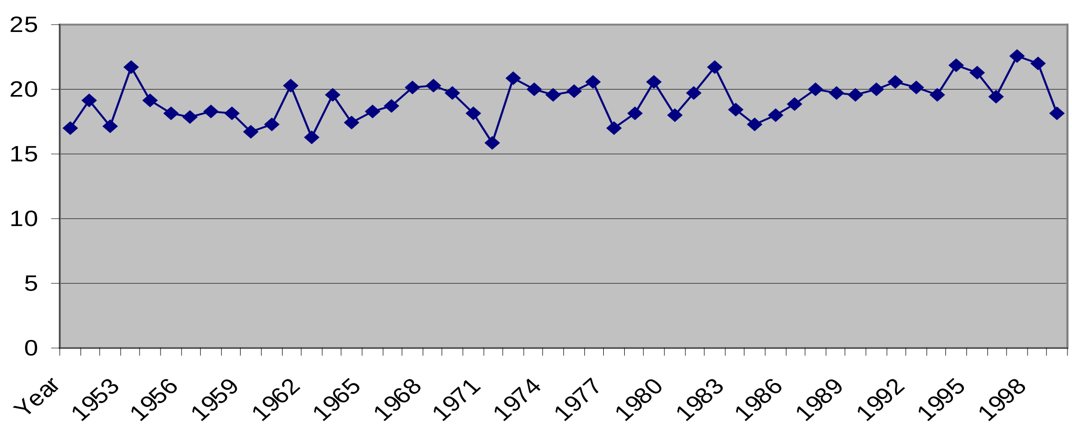


Figure 2-2 High-water levels from 1951 to 2001 (in meters).

Throughout history, people in PLR have built levees to mitigate flood impacts. Levees are also used to reclaim land for increased grain production and to accommodate population growth. As a result, a total of more than 10,000 km^2 of annually flooded land has been converted to farmland and settlements (Peng 1999). Levees can protect human lives and property from flooding, but extensive levee construction has also reduced water storage capacity and changed the flood regime of the lake (Dou et al. 1999; Ma et al. 2004; Wu et al. 2004). In addition to increasing the risk of dramatic flood catastrophes, more economic loss is involved when levees fail. The most recent disastrous flood in

1998 resulted in the failure of many important levees, which caused significant damage to the economy.

The levees in PLR are categorized as crucial levees, major levees, and minor levees based on the amount of enclosed farmland and the area of settlement they contain (Peng 1999; Jiang 2006; Figure 2-3). Crucial levees enclose more than $66.7km^2$ of farmland, in addition to large cities or county capitals, and were built high and strong (i.e., with concrete). Major levees are charged with protecting more than $33.3km^2$ of farmland. Minor levees protect less than $33.3km^2$ of farmland and are usually not well built or maintained by local people. To improve the lake's floodwater storage capacity, four levees were designated for floodwater storage by the government of Jiangxi in 1986. According to the policy, the storage levees should be breached to allow floodwater to discharge when lake levels at Hukou reach 18.7m. However, large areas of land have been intensively farmed within these polders, and they were not breached during the 1998 flood. After the 1998 flood event, the government implemented a policy called "Returning Farmland to Lake," which resulted in the abandonment of many minor polders. The abandoned levees were classified into two types: "partial return" and "complete return." In the partial return polders, villagers were resettled to higher ground, but farmland could still be cultivated. In the complete return polders, villagers were resettled and farmland was restored to wetland. The government regulations state that when the lake level reaches 18.7m, partial return levees with protected areas less than $6.67km^2$ will be breached, and when lake levels reach 19.8m, the partial return levees with protected areas of more than $6.67km^2$ will be breached.

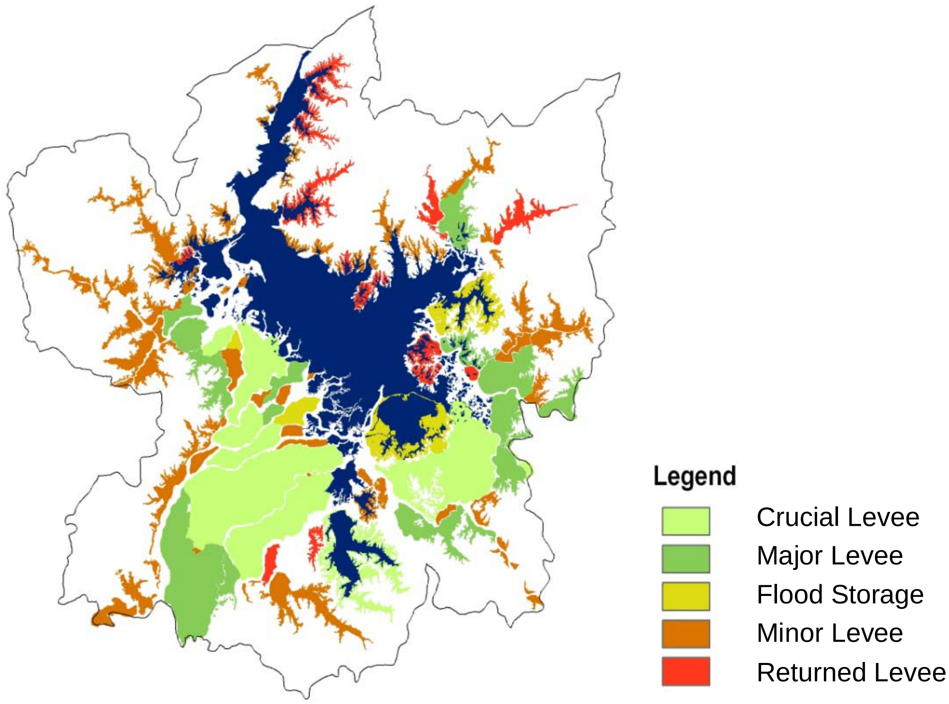


Figure 2-3 Polders and different types of levees.

New land-use practices that aim to reduce flood damage and increase land profitability have been developed by agricultural scientists in PLR (Yu 2002; Yuan et al. 2002a; Yuan et al. 2002b; Wang et al. 2002; Yuan et al. 2007). These practices include (i) new rice breeds with different growth cycles or rotation patterns that can avoid severe floods or (ii) spatial patterns planned based on elevation, such as growing more flood tolerable crops in low-lying areas. These practices have not been widely adopted, in part because government agencies have limited human and financial resources for promoting them, but also because farming households have small, fragmented landholdings.

PLR also possesses ecological importance. The coastal zone and wetlands around Poyang Lake serve as important habitats for more than 332 different species of birds, of which 13 are internationally protected, and the Siberian Crane is critically endangered. Natural reserves around Poyang Lake have been established for wildlife protection, but they are not sufficient to provide wintering habitat for the cranes, and the variety and extent of protected wetland habitats needs to be expanded (Bird Life International 2000; Kanai et al. 2002).

As with other rural areas in China, PLR has been experiencing rapid and dramatic social, economic, and political changes due to policy reforms at the national level. After 1949 and prior to policy reforms in the late 1970s, the development policies in China focused on heavy industries under strong central planning (Zhang and Chen 2005; Hui and Huo 2007; Yin 2008; Lin 2009). To support industrial development, prices for agricultural products were fixed at low levels, and production quotas were assigned to local governments. To increase agricultural production, from 1966 to 1978, communal farming systems were in place. In addition, because heavy industries had no need for large amounts of labor, rural residents were not permitted to migrate to urban areas. Migration was controlled by the household registration system (called Hukou), which differentiates urban and rural households. As a result, the gap between rural and urban areas grew with regard to development level and living standards. To promote agricultural production and rural development, the Chinese government began a series of policy reforms in the late 1970s that shifted production decisions to households and liberalized agricultural markets.

The policy reforms regarding agricultural markets were carried out gradually in several stages (Heerink et al. 2005). The period from 1978 to1984 saw the initiation of the Household Responsibility System, in which the commune system was dismantled, and farmland was contracted out to farmer households (up to 30 years). Prices for agricultural products were increased to encourage agricultural production, and a small portion of the production that exceeded a quota was sold at higher, but controlled, prices. The period from 1985 to 1993 saw a decrease in the state control on marketing and purchasing agricultural products. A dual price system was established for major products, like grain, oil-bearing crops, and pork, in which prices were fixed for the procurement quota, while surplus production was sold at market prices or negotiated contract prices. In 1993, procurement quotas were reduced and in some regions, even eliminated. In this period, other products, such as fruits and aquatic products, were freely traded on the market. The period from 1994 to 2003 marked the re-introduction of a government procurement system for grain as maintaining grain production and securing affordable food supplies became a priority for the Chinese government. To promote grain production, prices were increased to a level higher than world market prices, and the government spent a large amount of money subsidizing grain procurement, export, and storage. The Governor's Grain Bag Responsibility System was implemented, which gave provincial and local governments responsibility for agricultural production to ensure food self-sufficiency at the provincial level. The growth of the industrial sector, resulting from economic reforms, also created labor demand in urban areas. Beginning in 1991, the government liberalized urban jobs and implemented housing policies that encouraged rural-to-urban migration. Beginning in 2004, to further promote grain production, raise rural income, and be more in line with World Trade Organization (WTO) regulations, agriculture taxes were eliminated. Since then, subsidies have been given to grain-producing households for high-quality grain seeds and machinery. Additionally, public investments in rural infrastructure have been increased and off-farm work opportunities have been further stimulated.

These policy reforms have created an increasingly free-market economy in China and have a great impact on the livelihood of rural populations. During the initial reform period, agricultural production and rural income were marked by fast growth. Rural income, however, entered a stagnant period in the late 1980s, and the gap in income and living standard between rural and urban areas widened. As a large rural population does migratory work, farmland in the countryside is cultivated carelessly or left fallow in some places, and overall agricultural production is low. Currently, land-use rights can be exchanged between rural households through private negotiation, but the contracts are usually signed for short periods of time and lack security. Agriculture, Farmers and Rural Areas are identified as the Three Issues of rural development in China (Zhang et al. 2004; Zhang and Chen 2005; Shi et al. 2006; Green Book of China's Rural Development 2007-2008). Creating greater increases in agricultural production and rural household income has become a significant challenge for the Chinese government (Zhang et al. 2005; RDI/CASS and NBSC 2008). And PLR confronts additional challenges in development due to flood hazards.

References

Bird Life International (2000) *Threatened Birds of the World*. Bird Life Intl, Cambridge, UK.

Chen, W. and Zhao, X. (eds.) (2007) Land-use Patterns and Construction of Security Patterns in the Poyang Lake Region, China. China Agriculture Press, Beijing, China (in Chinese).

Dou, H., Min Q. and Shi, F. (1999) Impacts of reclamation on the flood regime of Poyang Lake and countermeasures. *Journal of Lake Sciences* 11(1), 24–27 (in Chinese).

Heerink, N., Qu, F., Kuiper, M., Shi, X. and Tan, S. (2007) Policy reforms, rice production and sustainable land use in China: A macro-micro analysis. *Agricultural Systems* 94(3), 784–800.

Huang, J. and Dai, S. (2004) Agricultural structure adjustment and industrial development in the Poyang Lake Region. *Journal of Nanchang University* 28(2), 34–139 (in Chinese).

Huang, G., Wang, S., Jiang, H., Zhao, X. and Shi, Q. (2006) Research on the development of plant industry in Poyang Lake and its surrounding economic zone. Journal of Jiangxi Agricultural University 5(4), 20-28 (in Chinese).

Hui, N. and Huo, L. (2007) *The Transition of Chinese Rural Excess Labor*. China Economic Publishing House, Beijing, China (in Chinese).

Jiang, L. (2006) *Flood Risk and Land Use Change in the Wetland Restoration Area Around Poyang Lake, China*. PhD Dissertation, Institute of Geographic Science and Natural Resources Research, Chinese Academy of Sciences, Beijing, China (in Chinese).

Jiang, L., Bergen, K. M., Brown, D. G., Zhao, T., Tian, Q. and Qi, S. (2008) Land-cover change and vulnerability to flooding near Poyang Lake, Jiangxi Province, China. *Photogrammetric Engineering and Remote Sensing* 74(6), 775–786.

Kanai,Y, Ueta, M., Germogenov, N., Nagendran, M., Mita, N. And Higuchi, H. (2002) Migration routes and important resting areas of Siberian Cranes. *Biol Cons* 106, 339–46.

Lin, J. Y. (2009) *Economic Development and Transition: Thought, Strategy, and Viability*. Cambridge University Press, Cambridge, UK.

Ma, D. (2007) *Analysis of Socio-economical Vulnerability to Flood in the Poyang Lake Region*. PhD dissertation, Institute of Geography and Natural Resources, Chinese Academy of Sciences, Beijing, China (in Chinese).

Ma, Y., Li, J. and Song, Y. (2004) The characteristics and trends of flooding in Poyang Lake. *National Natural Resources* 1(4), 40–44 (in Chinese).

Min, Q. (1997a) The flooding trends of Poyang Lake and strategies for flood protection and damage reduction. *Disaster Reduction in China* 7(2), 33–37 (in Chinese).

Min, Q. (1997b) The analysis of flood features in Poyang Lake. *Jiangxi Hydraulic Science and Technology* 23(2), 86–92 (in Chinese).

Peng, Z. (ed.) (1999). *Levee Atlas of Jiangxi Province*. Jiangxi Provincial Government Levee Department Publication (in Chinese).

Rural Development Research Institute/ Chinese Academy of Social Sciences (RDRI/CASS) and National Bureau of Statistics of China (NBSC) (2008) *Rural*

Economy of China: Analysis and Forecast (2007-2008). Social Sciences Academic Press, Beijing, China (in Chinese).
Shankman, D. and Liang, Q. (2003) Landscape changes and increasing flood frequency in China's Poyang Lake Region. *Professional Geographer* 55(4), 434–45.
Shi, Q., Pan, X., Du, T. and Wong, Z. (2006) *Jiangxi Agriculture Development Strategies*. China Agriculture Publishing House, Beijing, China (in Chinese).
Wang, D., Chen, W. and Ouyang, Y. (2002) A study on techniques of growing high-yield early rice in the flood-prone Yangzi River basin. *Journal of Jiangxi Agricultural University* 24 (4), 467–470 (in Chinese).
Wang, X., Yan, B. and Wu, G. (eds.) (2006) *The Program of Mountain-River-lake*. Science Press, Beijing, China (in Chinese).
Wu, D., Li, R. and Wang, Y. (2004) Analysis of the flood control and disaster relief situation after pushing over dykes and returning land to lake in the Poyang Lake Area. *Hydrology* 24(6), 26–31 (in Chinese).
Xu, D., Xiong, M. and Zhang, J. (2001). Analysis of hydrologic characteristics of Poyang Lake. *Yangtze River*, 32, 21–27.
Yin, P. (2008) *Study of China Rural Poverty under Social Exclusion*. Knowledge Rights Publishing House, Beijing, China (in Chinese).
Yu, Y. (2002) The application of several high-return production models for flood-damage-reduction agriculture in Nanchang County. *Jiangxi Agricultural Science and Technology* 3, 7–8 (in Chinese).
Yuan, Z., Xiao, Y. and Liu, G. (2002a) Research on selection of flood-damage-reduction short growth early rice breeds and their adaptability. *Jiangxi Agricultural Science and Technology* 6, 2–4 (in Chinese).
Yuan, Z., Xiao, Y., Liu, G. and Liu R. (2002b) Research on flood- damage- reduction rice rotation methods and their evaluation. *Jiangxi Agricultural Science and Technology* 5, 37–39 (in Chinese).
Yuan, Z., Xiao, Y., Liu, G. and Liu. R. (2007) Research and practice on flooding risk reduction agriculture in the Poyang Lake Region. *Journal of Jiangxi Agricultural University* 19(7), 112–114 (in Chinese).
Zhao, X. and Guo, X. (2001). The analysis of sustainable development and use of agricultural land resources in the Poyang Lake region. *Economic Geography* 21(4), 483–495 (in Chinese).
Zhang, X., Chen, X. and Wang, J. (eds.) (2004) *China Rural Reform and Development*. Wuhan University Press, Wu Han, China (in Chinese).
Zhang, X. and Chen, L. (2005) *Economic Development at the Village Level*. Wuhan University Press, Wu Han, China (in Chinese).
Zhu, H., Jin, F. and Li, R. (2002) *A Study of the Flood Storage Functions of Poyang Lake and Flood Damage Reduction.* Climatology Press, Beijing (in Chinese).

Chapter III

A Regional Assessment of Well-being

Introduction

This chapter presents a regional assessment of well-being in PLR. The assessment is intended to (i) provide scientific information for government policy-making regarding development in the context of flood hazards in PLR, and (ii) generate useful insights about future development of towns in PLR.

The assessment was carried out for 298 towns in PLR (governmental units two levels finer than the province). I used an innovative approach to map flood-risk zones with a digital elevation model, levee GIS data, and historical data on lake levels. The flood-risk zones reflect spatial variations of flood risk in PLR, and serve as the basis for measuring exposure of the towns to flooding. I then combined land-use data interpreted from remote sensing images and population distribution map with the flood-risk zones to derive measures of sensitivity of existing development to flooding. I used socio-economic data from the census to represent development level in three aspects: health, literacy and income. Assessments were performed and mapped using individual variables, and then combined to produce an assessment of overall well-being. Further, I examined the relationships between these measures of well-being and explored what other variables are associated with exposure, sensitivity, and development level at the town level. I also discussed practical implications of the assessment results for government policy making and for future development of the towns.

Data and methods

Mapping flood risk

Environmental flood risk is often described using the flooding frequency over a particular period (for example, 50 years or 100 years), which reflects the empirical probability that the location has been flooded in the past (Dunne and Leopold 1978). Historical records of flood events are often used to generate flood frequencies. Such data, however, are usually aggregated at high levels of administrative units or based on point samples collected with insufficient frequency to provide detailed spatial variability of risk over a large area. A continuous spatial surface of flooding frequency can be derived if maps of flood inundation over a multiple-year period are available. Satellite-based remote sensing images have been used to map the extent of flood inundation and provide an effective way to create maps of flood inundation over large areas (Deutsch et al. 1973; Bhavsar 1984; Wang et al. 2002; Andreoli et al. 2007; Qi et al. 2008). Unfortunately, satellite images are not yet available over a 50-year period.

To map flood-risk zones in PLR, I combined a 30m-resolution digital elevation model (DEM), GIS data on levee location, height and quality, and annual high lake levels between 1951 and 2001. Two things are essential in determining flood risk in PLR: elevation and levee construction. As a floodplain of Poyang Lake, the land in PLR close to the lake is flat and gradually rises further away from the lake. Levees affect flood risk by altering the natural terrain, but their effects vary with their quality and height.

A map of levees around Poyang Lake was created through interpretation of Landsat TM/ETM+ imagery, with additional information from published sources and field surveys (Jiang 2006). The levee GIS data was used to adjust the DEM in order to characterize the terrain as modified by levee construction. Based on adjusted elevations, historical high lake levels recorded at Hukou were used to produce a flooding frequency map. Flood-risk zones were then identified according to flooding probability.

Levees change the natural terrain as if lifting the protected areas to a new height. But because levees can fail, this virtual height does not provide the same level of protection as natural elevation. I borrowed the concept of discount rate from economics to discount the virtual height created by a levee and reflect its probability of failure. The modified elevation of a place behind a levee was computed as:

$$E' = E + (H - E)*R \tag{1}$$

Where E and E' are the DEM-based and modified elevations respectively, H is the levee height (elevation of the top of a levee), and R is the discount rate, which is an (inverse) indicator of a levee's failure probability. Because levee type indicates how well levees are constructed and maintained, and therefore, how often they are expected to fail (or be breached), I used a discount rate that was based on levee type according to published information on levee design and construction (Jiangxi Province Department of Water Resources 1999) and the opinions of local scientists. The discount rates were 98% for crucial levees, 95% for major levees, 98% for floodwater storages, 90% for minor levees, and 90% for return levees. For example, the 98% discount rate for crucial levees can be interpreted as indicating that these levees fail once every 50 years, or that they will stand strong against floods less severe than those that occur once every 50 years.

After the DEM was adjusted (Figure 3-1), historical data on lake levels (Figure 2-3) were used to generate a flooding frequency map. If the adjusted elevation of a place was lower than the high-water level of a year, it was counted as having flooded once. The total number of years in which the adjusted elevation of a place was lower than the high-water level from 1951 to 2001 was summarized to generate the flooding frequency over a 50-year period.

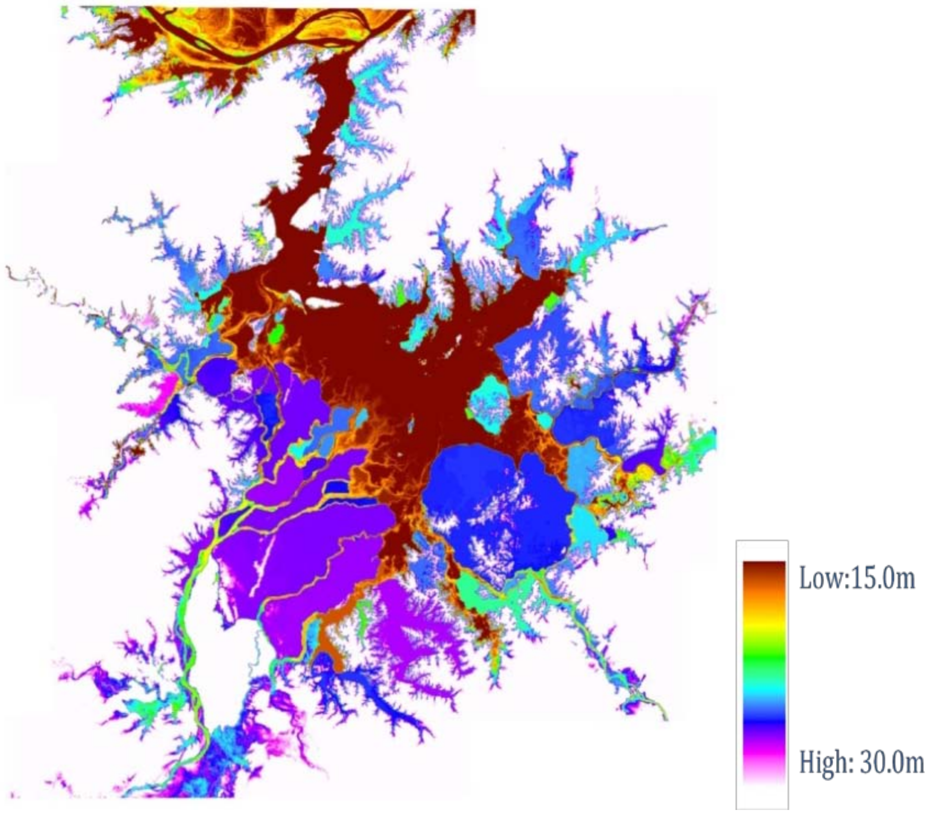


Figure 3-1 Elevations in PLR modified to represent the effects of levees. The area in white is above 30m.

The flood-frequency map was then classified to create flood-risk zones (Figure 3-2) using the definitions described in Table 3-1. These flood-risk zones allow us to evaluate the spatial variability of flood risk in PLR and serve as the basis for calculating exposure and sensitivity of human development to flooding. By classifying into zones, I retained the information on various locations' relative flood risk, while simplifying quantitative information about the flood frequencies.

Table 3-1 Definitions of flood-risk zones

Flood-Risk Zone	Flooding Frequency over 50 years (F)	Interpretation
Very low risk	F <=0	Never flooded
Low risk	0< F <=1	Flooded once every 50 years
Medium risk	1< F <=5	Flooded more than once every 50 years
High risk	5< F <=10	Flooded more than once every 10 years
Very high risk	F >10	Flooded more than once every 5 years

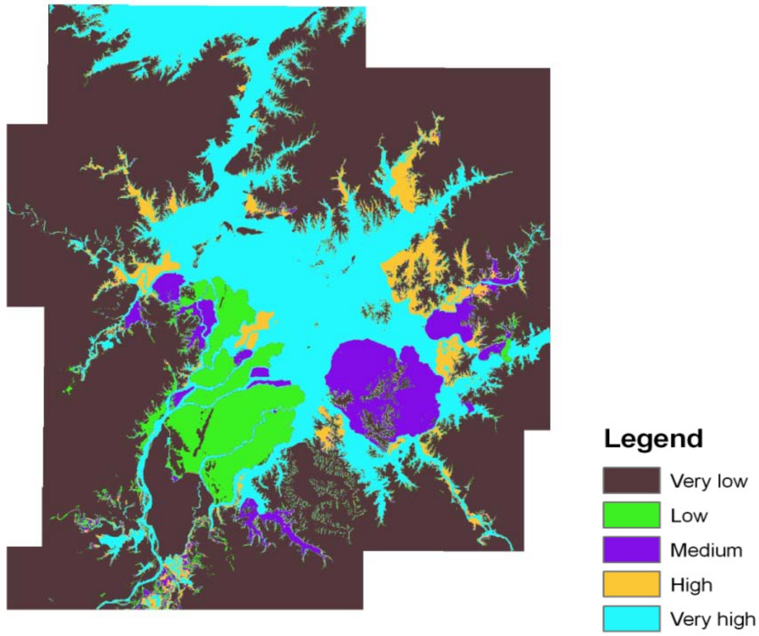


Figure 3-2 Mapped flood-risk zones in PLR.

Land-cover and population-density data

A land-cover layer (Figure 3-3) was interpreted from a pair of Landsat 7 ETM+ images on December 10, 1999 and July 5, 2000 (Jiang et al. 2008). Two images were used to cover land-use differences in the winter and the summer. With reference to field land-use data that were collected for 131 locations around Poyang Lake, the images were initially classified into seven land-cover categories: Paddy Rice, Upland Crops, Forest, Wetland/Water, Fishpond, Urban, and Bare land. Paddy Rice and Upland Crops, which were often mixed with vegetables or orchards, were then combined into a single Farmland category.

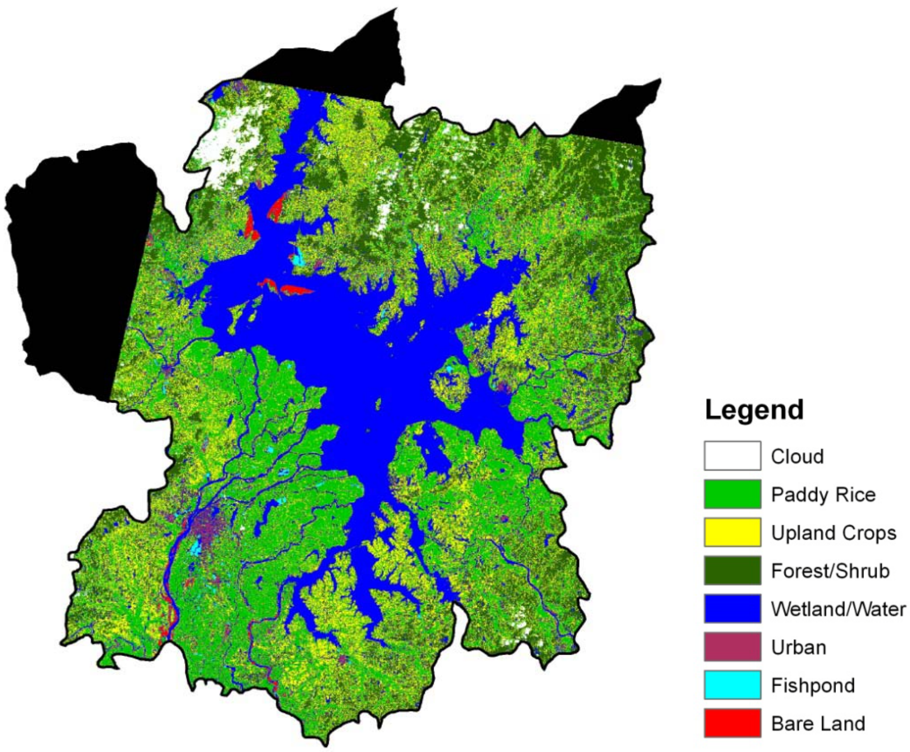


Figure 3-3 PLR land cover in 2000 (Jiang et al. 2008).

The China Data Center at the University of Michigan provided this study a population-density map at one sq km grid level (Figure 3-4) and a geographic data layer that approximates town boundaries in PLR. The population-density map was derived from population data at the town level from the 2000 census with references to other GIS data that included residential places, roads, rivers, lakes, elevations, administrative boundaries of counties and districts, and administrative areas of towns at 1:250,000 scale. The boundaries of towns were first defined using simple Theissen polygons around town administrative locations, and then adjusted dynamically with the areas of towns.

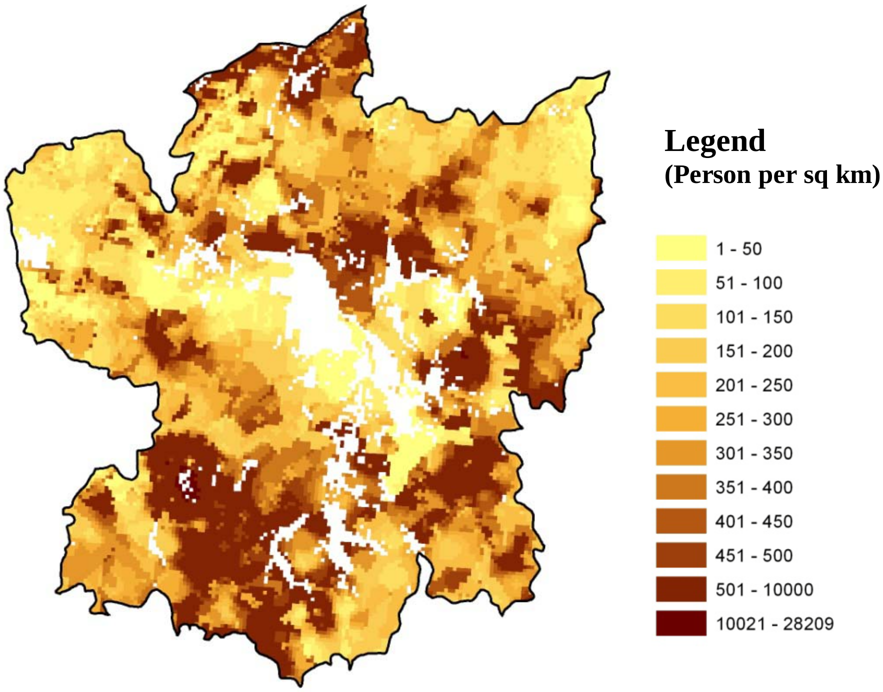


Figure 3-4 PLR population density in 2000 (CDC).

Measuring the well-being of towns

I used several variables to represent the three dimensions of well-being at the town level (Table 3-2). For the assessment, I reclassified the five flood-risk zones defined in Table 3-1 into three zones of high, medium, and low flood risk. The high flood-risk zone now included areas of high and very high flood risk, the low flood-risk zone included areas of low and very low flood risk, and the medium flood-risk zone remained the same.

Exposure was represented by the percentage of land in the high flood-risk zone because this measure reflects the biophysical environment of a town with respect to flood hazards and cannot easily be changed by the town.

Table 3-2 Summary of variables used in the regional assessment

Dimensions of Well-being	Variables	Measurement Scheme	
Exposure	Percentage of land in high flood-risk zone	Degree of exposure: Ist Quartile : 1 2nd Quartile: 2 3rd Quartile: 3 4th Quartile: 4	
Sensitivity	Percentage of people living in high flood-risk zone Percentage of farmland in high flood-risk zone	Degree of sensitivity of human lives: Ist Quartile : 1 2nd Quartile: 2 3rd Quartile: 3 4th Quartile: 4 Degree of sensitivity of farmland: Ist Quartile : 1 2nd Quartile: 2 3rd Quartile: 3 4th Quartile: 4	**Overall sensitivity:** the HIGHER of the two
Development Level	Number of households spending 50,000yuan (or more) in building or purchasing house per thousand households	Rank the values from low to high for all towns, and then group every 30 towns into one category. The first category scores 1, The second category scores 2, …	**Overall development level:** the SUM of the three
	Percentage of people with a high school diploma (or above)	Rank the values from low to high for all towns, and then group every 30 towns into one category. The first category scores 1, The second category scores 2, …	
	Number of deaths per thousand infants under one year old	Rank the values from high to low for all towns, and then group every 30 towns into one category. The first category scores 1, The second category scores 2, …	

The percentage of people and the percentage of farmland in the high flood-risk zone were used to represent sensitivity of human development to flooding because these measures reflect the outcome of interactions between human activities and the biophysical environment with respect to flood hazards, as well as how human development can be affected by flooding. Unlike the measure of exposure (percentage of land in the high flood-risk zone), these sensitivity measures are changeable. Human lives and economic activities are two essential components to consider in examining the impact of climatic hazards. Because the major economic activities in PLR are agricultural, the spatial pattern of farmland is important. I used ArcGIS to derive these sensitivity measures. The percentage of the population that inhabits the high flood-risk zone was calculated by overlaying the population-density surface (Figure 3-4) with the flood-risk zones map (Figure 3-2) and summarizing across towns. Similarly, the percentage of farmland was calculated by overlaying the farmland surface (Figure 3-3) on the flood-risk zones map.

I used three variables to represent human development with regard to income, literacy, and life expectancy. They were the closest match to UNDP's human development measures (UNDP 1990; 2007; 2008) from among the variables available in the 2000 census data (provided by the China Data Center at the University of Michigan) at the town level in PLR. Because income was not reported in the census, the number of households per thousand that spent at least 50,000CNY in building or purchasing a house was used to capture economic development. The percentage of the population with at least high school education and the number of deaths per thousand infants under one year old were used to capture broader social aspects of development. The infant mortality rate is related to health, and reducing infant mortality rate has been specified as a major Millennium Development Goal (MDG 2008).

Using quartile assignments on each of the three dimensions provides the regional government with a good understanding of PLR towns' relative development, exposure, and sensitivity levels. These assignments also reduce the amount of information to make the assessment easily accessible to policy makers, and remedy the problem created by the lack of a direct measure of income.

All variables were summarized for each town in PLR with ArcGIS, using the map of approximate town boundaries. Due to incomplete coverage in the satellite images, I was able to collect land-cover data for only 270 of the 298 towns in PLR. I mapped spatial patterns of well-being using individual variables, and then combined multiple measures to map each of the three dimensions of well-being (Table 3-2).

I also explored correlations among the different measures to understand relationships between measures used for each of the three dimensions of well-being. Based on mapped patterns of exposure, sensitivity, and development level, I further explored what factors were associated with the different dimensions of well-being at the town level. For this analysis, I used the percentage of rural population from the 2000 census data. Additionally, I calculated the distances of each town to Poyang Lake and to the closest county capital based on point GIS data of towns, county capitals, and the boundary map of Poyang Lake using ArcGIS.

Results

About one third of the land and one fifth of the farmland in PLR are at risk of being flooded more than once every ten years. Approximately one quarter of the population lives in a location at risk for flooding more than once every ten years (Table 3-3). Variation in well-being among the towns in PLR is large in each dimension (Table 3-4).

Table 3-3 Land, population and farmland in each flood-risk zone in PLR

Flood-Risk Zone	Area of Land	Population	Area of Farmland
Low risk	63.3%	68.2%	73.8%
Medium risk	7.4%	8.6%	15.5%
High risk	29.3%	23.2%	21.6%
Total	19,874 km^2	7,955,966 persons	7,849 km^2

Table 3-4 Descriptive statistics of well-being of towns

	Pct. land in the high flood-risk zone (%)	Pct. people in the high flood-risk zone (%)	Pct. farmland in the high flood-risk zone (%)	Number of households per thousand spending 50,000CNY (+) in housing (‰)	Pct. people with a high school (+) diploma (%)	Number of deaths per thousand infants under one year (‰)
Min	0.0	0.0	0.0	0.0	2.5	0.0
Median	13.7	13.6	10.4	16.0	6.3	17.0
Mean	25.6	25.2	20.6	45.7	11.9	31.7
Max	99.8	99.8	99.9	459.2	76.7	352.2
SD	29.0	28.5	24.7	92.6	13.1	56.8

Variables representing exposure and sensitivity exhibited similar spatial patterns, wit both exposure and sensitivity appearing higher closer to the lake (Figure 3-5; Figure 3-7). The percentage of land in the high flood-risk zone and the distance to Poyang Lake were negatively correlated (Figure 3-6a), and the difference in mean distance to the lake between every two levels of exposure (i.e., by quartile) was significantly different than zero ($p < 0.01$), with the exception that p is 0.0979 between the second and third levels (Figure 3-6b).

Variables used to represent sensitivity were closely related to exposure. Specifically, the percentage of population in the high flood-risk zone and the percentage of farmland in the high flood-risk zone were both significantly correlated with the percentage of land in the high flood-risk zone (Figure 3-6c; Figure 3-6d). The relative level of sensitivity was identical to the relative level of exposure for most towns (247 towns), and only 17 towns have sensitivity one level lower than exposure (Table 3-5).

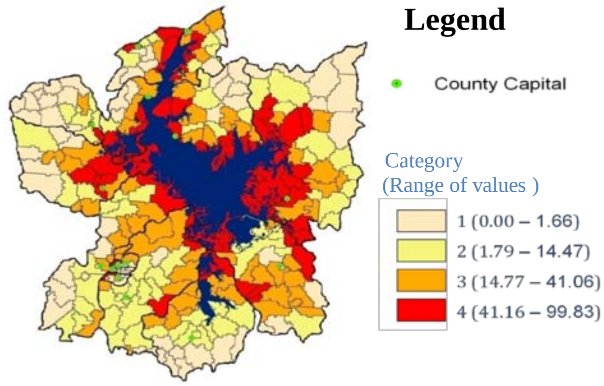


Figure 3-5a Exposure

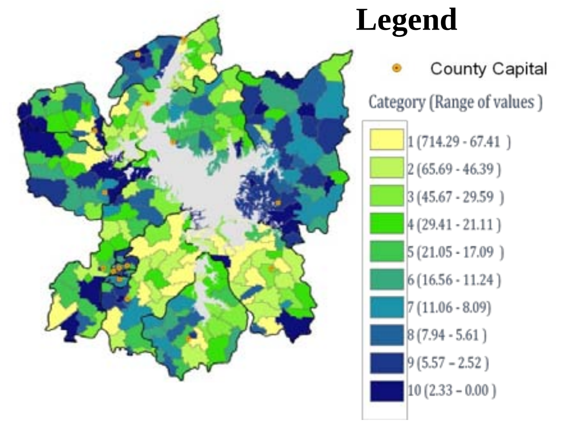


Figure 3-5f Development Level - Infant Mortality Rate

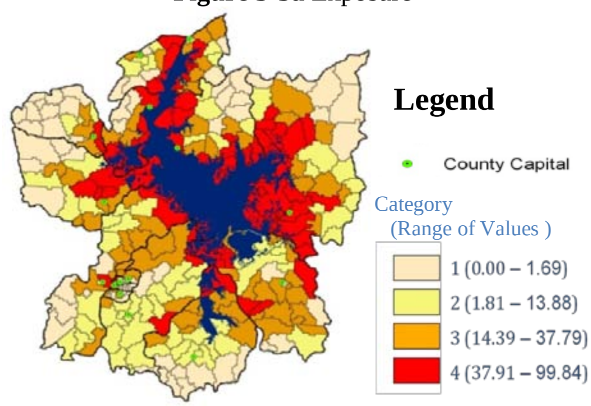


Figure 3-5b Sensitivity - Population

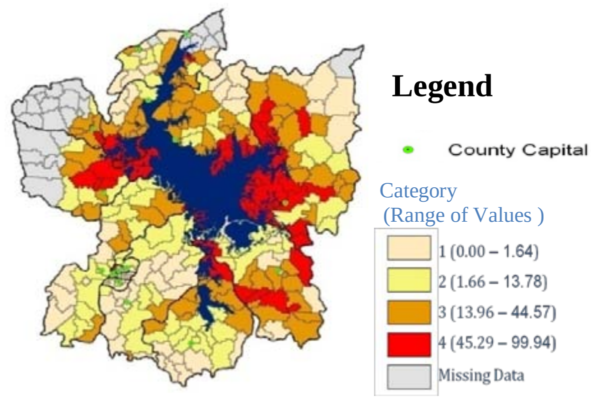


Figure 3-5c Sensitivity - Farmland

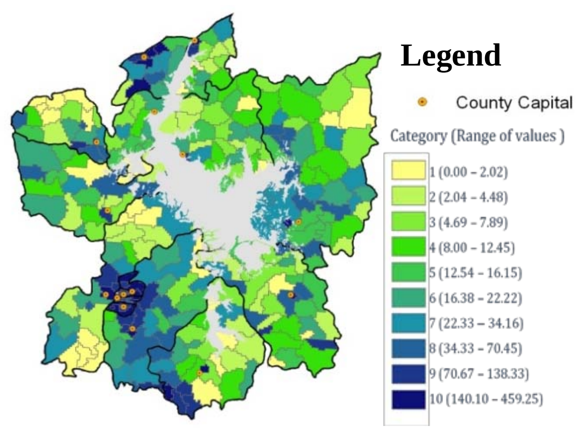


Figure 3-5d Development Level - Housing

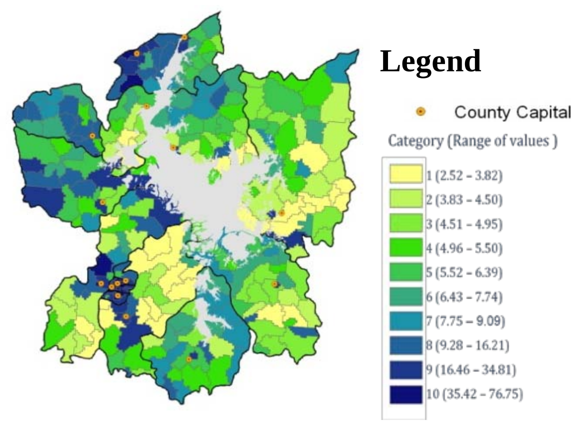


Figure 3-5e Development Level - Education

Figure 3-5 Mapped patterns of each variable.

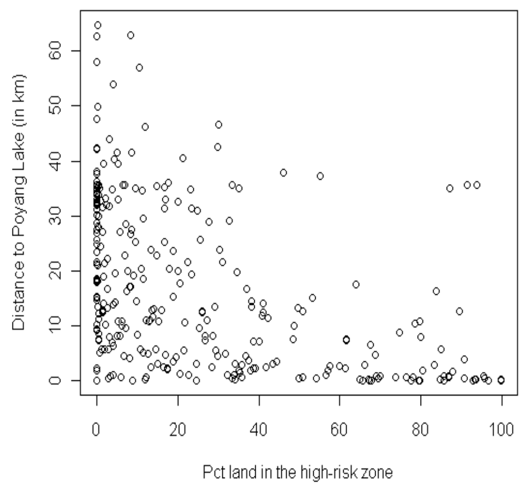


Figure 3-6a (cor = -0.4723)

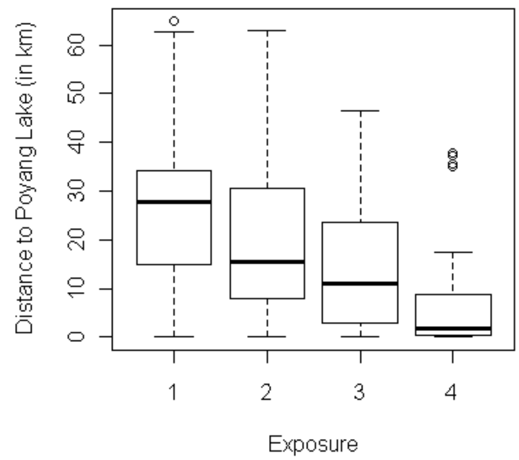


Figure 3-6b

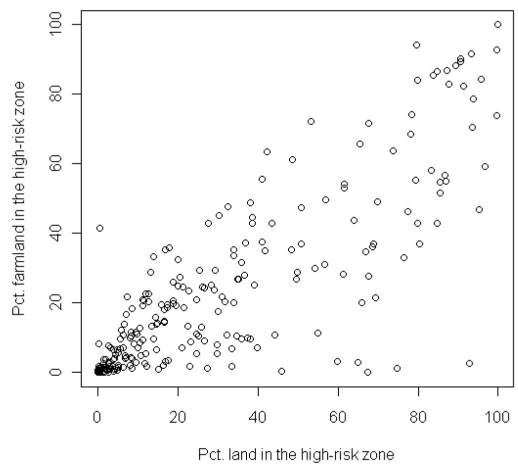


Figure 3-6c (Cor = 0.8629)

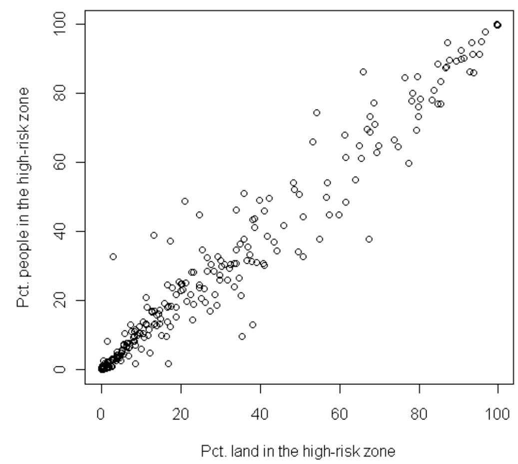


Figure 3-6d (Cor = 0.9747)

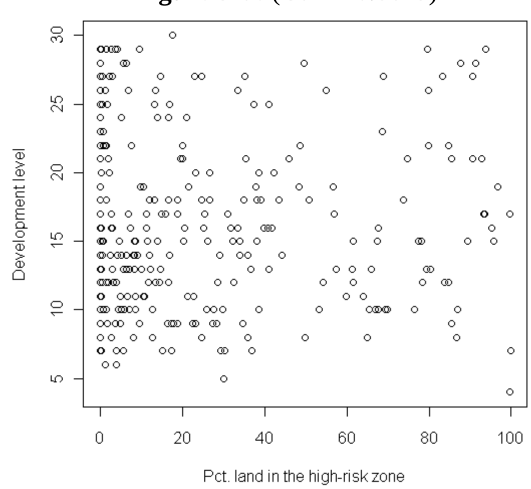


Figure 3-6e (Cor = 0.0187)

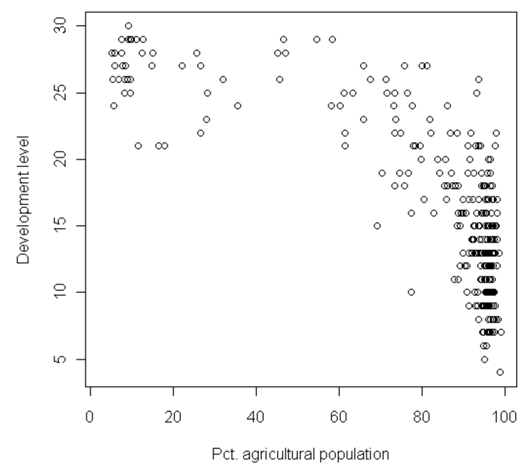


Figure 3-6f (Cor =-0.6058)

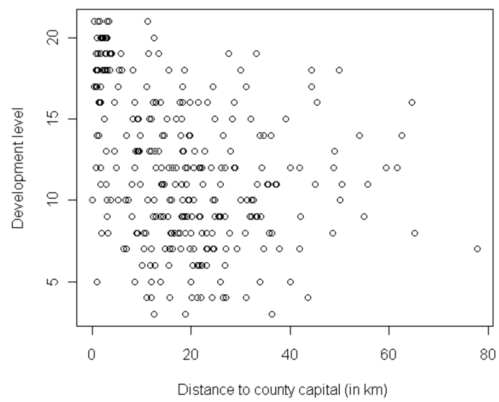


Figure 3-6g (Cor =-0.3062)

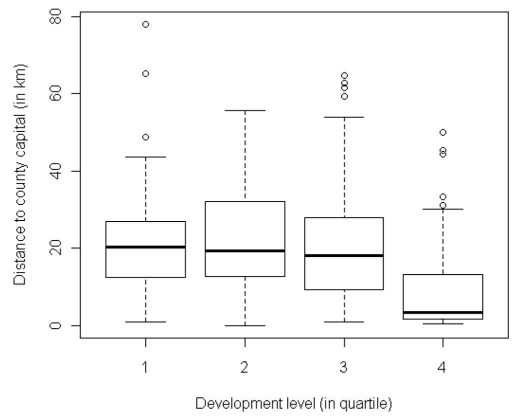


Figure 3-6h

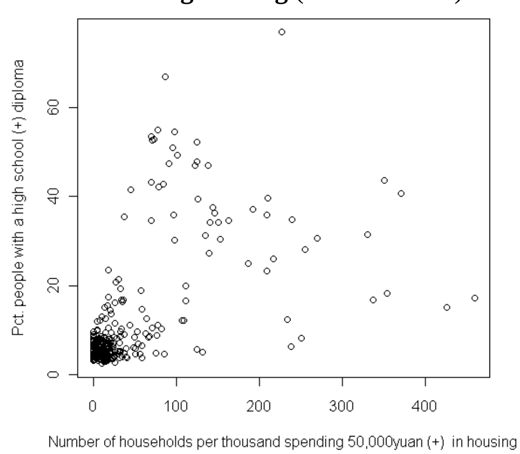


Figure 3-6j (Cor = 0.5599)

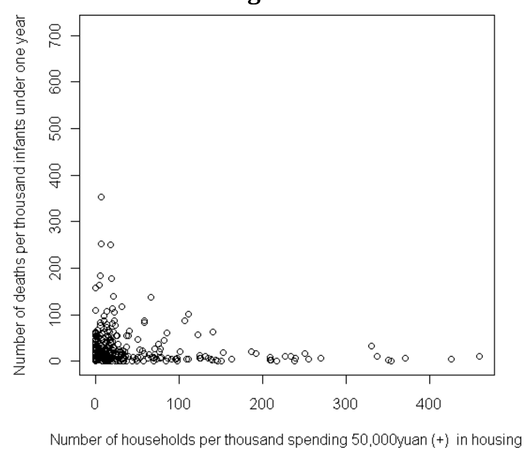


Figure 3-6k (Cor =-0.1720)

Figure 3-6 Relationships between the variables.

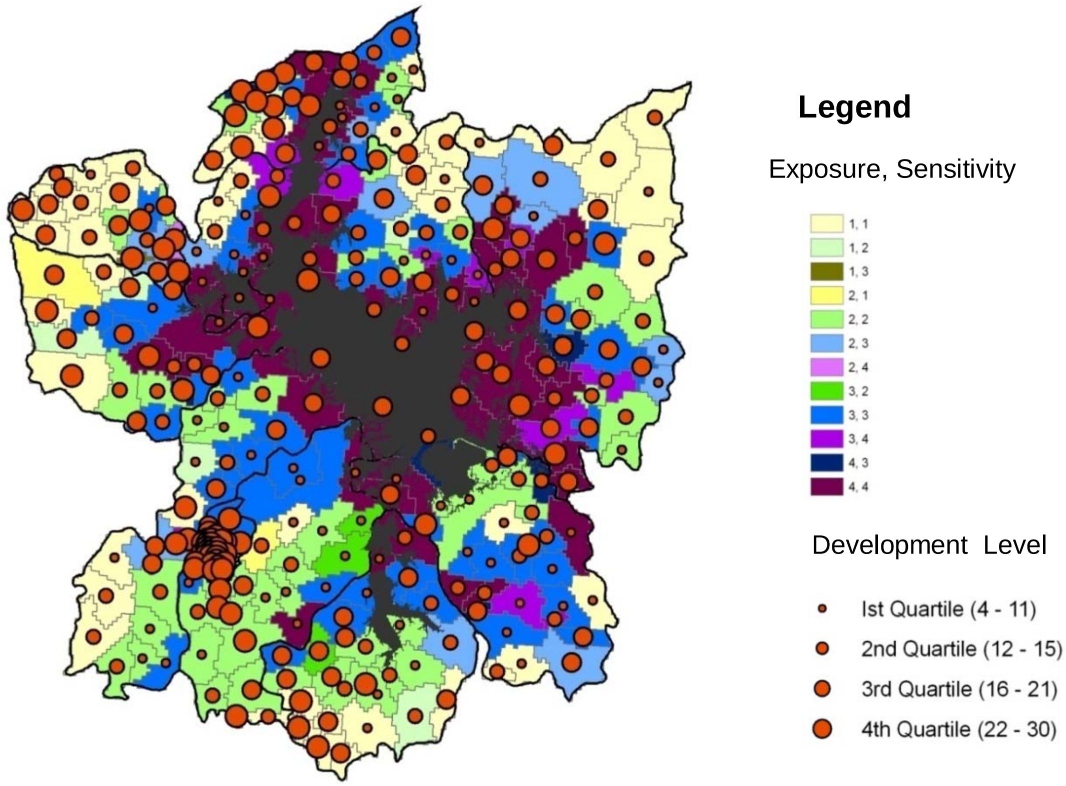


Figure 3-7 Classification of towns according to the three dimensions of well-being.

Table 3-5 Distribution of towns among quartiles of exposure, sensitivity and development level

Exposure Score	**Sensitivity** Score (Number of Towns)	**Development Level** (Number of Towns)			
		1^{st} Quartile	2^{nd} Quartile	3^{rd} Quartile	4^{th} Quartile
1	1 (67)	13	16	14	24
	2 (8)	1	2	2	3
	3 (1)	0	0	0	1
	Total	***14***	18	16	27
2	1 (4)	0	1	1	2
	2 (58)	17	21	8	12
	3 (13)	4	4	5	0
	4 (1)	0	0	0	1
	Total	21	26	14	15
3	2 (6)	2	0	2	2
	3 (59)	19	11	21	8
	4 (11)	3	4	3	1
	Total	24	15	26	11
4	3 (7)	0	2	2	3
	4 (62)	***16***	16	18	***12***
	Total	16	18	20	***15***

Development levels did not demonstrate a spatial pattern similar to that of exposure (Figure 3-5) and were not associated with exposure (Figure 3-6e). There are some towns in which exposure and development influence the population in opposite directions. Fourteen towns had exposure and development levels both in the lowest quartile, and fifteen towns had exposure and development levels both in the highest quartile (Table 3-5).

Variations in development level appeared to be more related to location relative to cities (Figure 3-5; Figure 3-7) and degree of urbanization (Figure 3-6f). The correlation between development level and distance to county capital were not strong among all towns (Figure 3-6g), but the mean distance to the county capital for towns in the highest quartile of development level was significantly smaller than that of towns in other quartiles ($p < 0.001$) (Figure 3-6h). Development level and the percentage of rural population were negatively correlated (Figure 3-6f).

There is a distinct difference in development level between less and more rural towns (Figure 3-6f). All fifty-three towns with a rural population below 70% have a development level score over 20 (the maximum is 30) with an average of 26. When the rural population percentage was 70% or above, the development level was, on average, much lower (14) and also spread more widely. The rural population percentage alone explained 57% of the variation in development level among all towns, and 38% of the variation in development level among towns with 70% or more rural population. In both cases, the relations were significant ($p<0.01$).

Development levels in housing, education, and health did not appear to have similar spatial patterns (Figure 3-5). The housing variable and the education variable were correlated to some degree (Figure 3-6j). However, the housing variable was not correlated with the health variable (Figure 3-6k), suggesting that a higher level of economic achievement does not guarantee improved heath.

Discussion

Measures of exposure, sensitivity, and development provide a comprehensive assessment of the well-being at the town level in PLR (Figure 3-7). The assessment also suggests different future development pathways in different places and the need for different policy interventions to improve well-being. Several types of towns deserve particular attention (Table 3-6).

Towns with an extremely high degree of exposure and sensitivity and low level of development could be candidates for wetland restoration or natural reserves. “Returning Farmland to Lake” is a first step that the government has taken towards a more ecologically-sound means of flood mitigation. This assessment provides some useful information for the government to move further in this direction. For these purposes, additional information on local-scale variations in lake hydrology and wetland habitats need to be combined with the measures here to prioritize preserves based on both habitat quality and human well-being.

Table 3-6 Different types of towns and possible implications

Exposure	Sensitivity		Development Level	Implications
	Human Life	Land Use		
Extremely High	**Extremely High**		**Low**	Candidates for wetland restoration or natural reserves.
High	**Extremely High**			Induce or help people migrate away in the long run.
High		**High**		Promote flood-damage-reduction agricultural practices.
Low			**Low**	Look for reasons for low development level in the social system.
High	**High**		**High**	Make adjustments & strengthen levees.
Sensitivity is higher than Exposure				Examine development & make adjustments.

For highly exposed towns whose populations are extremely sensitive, policies that induce people to migrate out may be necessary in the long run. Extremely high levels of exposure alone can reduce human well-being to such a low level that out-migration is perhaps the best solution, particularly when human life is threatened. Given long-established livelihoods tied to a particular place, it can be very difficult for households to move to a new place. Therefore, assisting farmer households in finding new livelihoods in cities or elsewhere (with a particular focus on future generations through education) should be a key aspect of migration efforts. Without such efforts, migration will be a failed strategy. In PLR, some farmers who were resettled under the Returning Farmland to Lake Policy returned to farm the land that was restored to wetland because they were unable to acquire new livelihoods (Jiang 2006). Twelve towns in PLR had more than 90% of both their land and people in the high flood-risk zone, of which 5 had more than 95% of both land and people in the high flood-risk zone.

For those towns whose farmland is highly sensitive to flooding, agricultural practices that can reduce flood damage are important for achieving sustainable development, especially because agricultural production still significantly contributes to economic output in PLR. New land-use practices that can reduce flood damage and increase agricultural profitability need to be further promoted in such places. The information generated by this assessment can help government agencies target dissemination efforts to places that need them the most. Thirty towns in PLR had more than 50% of their farmland in the high flood-risk zone, and only three of them had less than 50% of their land in the high flood-risk zone. Thirteen towns had more than 80% of both their land and farmland in the high flood-risk zone.

Towns that are not highly exposed to flooding but have low levels of development may need to examine social systems to look for ways to increase their development level in the future. China's economy has experienced rapid growth since economic and policy reforms began in the late 1970s. However, in the transition from a centrally planned economy to a free-market economy, many governmental barriers exist that hamper development. For instance, some government officials misuse their power to pursue their own economic gains; corruption is widespread. Besides establishing and following good ethics, local governments need to have a clear understanding of various aspects of local development, including what and where the problems are, so as to improve the social-economic-political processes and create a fair and more favorable environment for their citizens. Fourteen towns in PLR had both exposure and development levels in the lowest quartile. Identifying the causes and possible solutions to address low development levels in these towns was beyond the scope of this dissertation.

Towns with degrees of sensitivity higher than exposure (34 towns in total) may need to examine their development patterns carefully to further reduce sensitivity. For those towns with high levels of development and high degrees of exposure and sensitivity, strengthening engineering work (i.e. levees) may be necessary to reduce exposure and sensitivity, in addition to making appropriate adjustments to development. Twelve towns in PLR had development, exposure, and sensitivity levels all in the highest quartile.

Conclusions

This assessment indicates that overall development in PLR is highly exposed and sensitive to flooding. Additionally, there are large variations in development level, exposure, and sensitivity among the 298 towns in PLR. Sensitivity is closely related to (and perhaps bound by) exposure; both levels are higher closer to the lake. The development levels, however, are more closely associated with degree of a town's urbanization, and higher development levels are found in towns closer to county capitals. To increase overall human well-being, only focusing on economic growth is not sufficient. Town governments need to look at broader aspects of development. As an economically less developed rural area, PLR needs to further promote development across towns. In the context of flood hazards, several types of towns deserve particular attention for future development. Each town may have different sustainable development pathways and need different policy interventions.

This assessment's practical significance for policy-making is limited by the paucity of data at the town level in PLR. Direct measures of income would better capture the economic aspect of human development. It would also be useful to recalculate these measures with more recent data to understand the current situation as well as perform a series of assessments using data in multiple time periods to examine the system's evolution and detect change trends.

References

Andreoli, R., Yesou, H., Li, J. and Desnos, Y. (2007) Synergy of low and medium resolution ENVISAT ASAR and optical data for lake watershed monitoring: Case study of Poyang Lake (Jiangxi, P.R. China). Paper Presented at *ENVISAT Symposium 2007,* Montreaux, Switzerland, April 2007.

Bhavsar, P. (1984) Review of Remote Sensing Applications in Hydrology and Water Sources Management in India.*Advances in Space Research*, 4(11), 193–200.

Deutsch, M., Ruggles, F., Guss, P. and Yost, E. (1973) Mapping the 1973 Mississippi Floods from the Earth Resource Technology Satellites. In: *Proceedings of the International Symposium on Remote Sensing and Water Resource Management*, Burlington, Canada: American Water Resource Association, No. 17, 39–55.

Jiang, L. (2006) *Flood Risk and Land Use Change in the Wetland Restoration Area Around Poyang Lake, China*. PhD Dissertation. Institute of Geographic Science and Natural Resources Research, CAS, Beijing, China (in Chinese).

Jiangxi Province Department of Water Resources (1999) *Levee Atlas of Jiangxi Province*. Nanchang, China (in Chiense).

Wang, Y., Colby, J. D. and Mulcahy, K. A. (2002) An efficient method for mapping flood extent in a coastal floodplain using Landsat TM and DEM data. *Int. J. Remote Sensing*, *23*(18), 3681–3696.

Dunne, T. and Leopold, L. B. (1978) *Water in Environmental Planning*. W. H. Freeman, San Francisco.

Jiang, L., Bergen, K. M., Brown, D. G., Zhao, T., Tian, Q. and Qi, S. (2008) Land-cover change and vulnerability to flooding near Poyang Lake, Jiangxi Province, China. *Photogrammetric Engineering & Remote Sensing*, 74(6), 775–786.

Ma, D. (2007) *Analysis of Socio-economical Vulnerability to Flood in the Poyang Lake Region*. PhD Dissertation. Institute of Geographic Science and Natural Resources Research, CAS, Beijing, China (in Chinese).

Millennium Development Goals (MDGs) (2008) Available at http://siteresources.worldbank.org/DATASTATISTICS/Resources/MDGsOfficialList2008.pdf

Qi, S., Brown, D. G., Tian, Q., Jiang, L., Zhao, T. and Bergen, K. (2009) Inundation extent and flood frequency mapping for the Poyang Lake, China, floodplain using Landsat TM and DEM. *GIScience and Remote Sensing,* 46(1), 101–127.

UNDP (1990, 2007, 2008) *Human Development Reports*. Available at http://hdr.undp.org/en/reports.

Chapter IV

An In-depth Analysis of Well-being and its Underlying Causes

Introduction

This chapter presents an analysis of multi-level and multi-source causes underlying the well-being of rural households in PLR. This analysis is intended to generate useful insights for government policy-making regarding rural development, as well as for rural households about how to increase their overall well-being, by focusing on household livelihood and integrating multiple perspectives of social vulnerability analysis, sustainable livelihoods framework, and development economics.

Social vulnerability usually refers to a particular group or social unit, embedded in a social-economic-political structure, unable to withstand adverse impacts when exposed to disruptive events (Sen 1981; Hewitt 1983; Watts 1987; Swift 1989; Sen and Dreze 1990). Understanding the social, economic, and political factors/processes (Watts and Bohle1993; Blakie et al. 1994; Ribot 1996 and 2009) that affect vulnerability of such people or groups is an important part of social vulnerability analysis. Socio-economic status, access to resources, age and gender, the degree of urbanization, occupations, infrastructure, education, and social capital are often assessed collectively to measure social vulnerability (Cutter et al. 2003; Adger et al. 2004; Dwyer et al. 2004; Vincent 2004; Brooks et al. 2005; Rygel et al. 2006; Ma 2007). However, how these factors determine social vulnerability is not fully understood, and their effects are likely to vary in different contexts. Diversified household-livelihood profiles are often found associated with lower vulnerability (Adger et al. 2002; Eakin 2003 and 2005; Eriksen et al. 2005; Steimann 2005; Eakin et al. 2006).

The sustainable livelihoods framework (DFID 1999, 2000 and 2001) is widely used to study the well-being of a person or household for development assistance (Ashley and

Carney 1999; Bebbington 1999; Ellis and Mdoe 2003; Allison 2005; Neely et al. 2005; Bhandari and Grant 2007). Under this framework, poverty is explained as the outcome of possessing ineffective livelihood strategies, which are chosen within the context of accessible assets and the constraints of policy and institutional processes. Livelihood assets are categorized into human capital (labour capacity, education, skills), natural capital (land, common property resources), physical capital (water supply, housing, communication facilities), social capital (social status, gender, links with family and friends, reciprocal exchange), and financial capital (wages, access to credits).

While social scientists sometimes emphasize the importance of structural and cultural settings, economists often treat households as economic agents that maximize production and utility. Though many empirical cases contradict perfect rationality, there is plenty of evidence that suggests a peasant's behaviors still exhibit an attempt to improve his/her condition (Strauss and Thomas 1995). And many apparently irrational behaviors may be successfully explained as a result of more complex exercises in rationality, particularly with deeper probes into the nature of constraints or preferences.

While quantitative methods are often used by economists to model household decisions and explore the roles of capital, education, demographics, technology, location, and institution in development at the household level (Psacharopoulos 1985; Kremer 1993; Foster and Rosenzweig 1996; Udry 1996; Deaton 1997; Bardham and Udry 1999; Card 2001; Jalan and Ravallion 2002; Duflo 2003; Schultz 2004; Banerjee and Iyer 2005; Banerjee et al. 2007; De Mel et al. 2008), sociologists and anthropologists also use qualitative methods, such as interviews and observations, to study human subjects (Susan 1977; James 1985; Jellinek 1997; Eades 2003). Because quantitative analyses are good for finding patterns with large datasets, and qualitative approaches allow us to develop in-depth understandings about underlying processes and look at social factors that are hard to quantify, they can complement each other in analyzing and understanding the underlying causes of well-being.

I combined quantitative and qualitative data and methods to demonstrate which social, institutional and environmental factors, and how they affect the well-being of individual households as a result of their land-use and livelihood decisions. I used both social and economic perspectives to guide my investigation of the land-use and livelihood decision-making processes of households. I identified the major livelihood profiles among households, and analyzed the characteristics of individual households and external conditions that contribute to the success of each profile. In addition, I looked into the composition of the livelihoods and the growth cycles of major crops in relation to flood dynamics to examine the sensitivity of human development (as defined in Chapter 1) at the micro level.

A total of 197 households in eight villages of different types were surveyed, and 69 farmer households, village leaders and local government officials were interviewed using open-ended questions. Based on this analysis, I provide some policy recommendations to resolve the three rural development issues (as outlined in Chapter II). I also discuss the implications of the findings with regard to government development policy-making in the context of flood hazards and for the local people in PLR.

Data and methods

Survey village selection

For the surveyed villages to reflect various types of human and physical environments in PLR, the villages around Poyang Lake were stratified by variables representing the physical environment and location relative to urban centers. Eight villages were chosen from a total of 359 villages that are within 12km distance of the lake and on the west side of the lake.

Elevation was used to capture variations in the natural environment because it is an important physical feature affecting agricultural practices and flood risk in PLR. Throughout history, levees have been constructed to reclaim farmland and protect lives and properties of the residents around Poyang Lake. The levees affect land use and flood risk by altering the natural terrain. To account for the effects of levees, I adjusted a digital elevation model (DEM) with GIS data that represent levee location and height. Locations in the modified DEM were assigned the height of the levee that protects it or the recorded elevation, whichever was higher. I classified villages into two types based on adjusted elevations: high elevation (and low risk) and low elevation (and high risk).

Distance to the county capital was used to represent the location of a village relative to urban centers. In China, county capitals are consistently much larger than other towns in the county and serve as the center of economic and administrative activities for the county. I classified villages into two types: close to city (within 5km) and far from city (beyond 5km).

Adjusted elevation and distance-to-county-capital formed a two-by-two matrix from which four types of villages were identified and six candidate villages of each type were randomly selected. Information about production structure, migration labor, income per capita, farmland per capita, number of households, and population of these villages was then collected through field trips. Based on this information, two villages of each type were chosen, for a total of eight villages. Due to road construction at the time of survey, three pre-selected villages were replaced by other nearby villages that had characteristics similar to the originally selected villages (Figure 4-1).

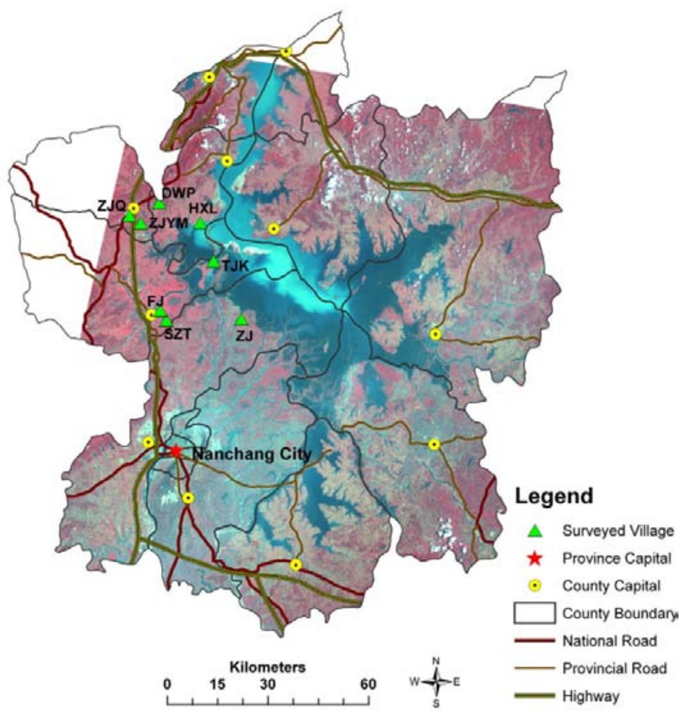


Figure 4-1 Surveyed villages.

Household surveys

Surveys were field tested in the summer of 2006, then conducted orally in January 2007, just before the Spring Festival[1], in order to increase the chance that potential respondents would be at home. Twenty-five percent of the households in each village were randomly chosen for survey (Table 4-1). Due to the availability of households at the time of survey, the actual proportion of surveyed households in each village was slightly different from 25%.

Table 4-1 Basic characteristics of the surveyed villages

Village		ZJ	TJK	FJ	SZT	ZJYM	ZJQ	DWP	HXL
Village ID		34	41	22	13	15	26	47	48
Surveys and Interviews	Number of. Households Surveyed	23	20	23	19	21	19	35	33
	Number of Households Interviewed	13(3)	15 (2)	2	3	5 (1)	3(1)	3(1)	15(2)
Flood Risk	Flood Risk	2	5	3	3	4	4	1	5
Location	Close to County Capital	N	N	Y	Y	Y	Y	N	N
Income per capita (in CNY)	Total	4280.9	4972.2	4673.7	3238.2	5476.7	5989.8	3978.4	3612.2
	Crop Cultivation	1803.9	338.5	1202.9	1162.4	466.4	2674.4	245.0	201.7
	Forestry	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0
	Livestock	183.5	80.8	0.0	2.2	338.1	203.3	41.1	124.3
	Fishing	4.6	1444.4	0.0	0.0	0.0	0.0	0.0	351.4
	Aquaculture	183.5	464.6	0.0	0.0	0.0	0.0	0.0	0.0
	Other sources	66.7	57.0	86.3	410.2	123.7	186.4	128.7	168.5
	Agricultural Wage	97.7	112.1	0.0	14.8	100.8	138.9	202.5	5.7
	Non-agricultural Wage	1681.7	1257.6	3037.9	1593.7	3011.9	1051.1	1903.3	2366.3
	Salary-based	80.4	227.3	87.9	0.0	466.1	1586.7	1288.1	354.3
	Business	178.9	989.9	258.6	54.9	957.6	148.9	169.8	40.0
	Pct. Off-farm Income	47.62	89.58	72.42	51.37	82.83	48.84	57.72	76.58
Loans	Avg. Amount of Loans	7217.4	15375	8217.4	4394.7	857.1	1947.4	6314.3	7348.5
	Pct. Bank Loans	0.60	32.51	35.18	0.00	0.00	13.52	1.81	5.57
	Pct. Loans Used for Business	0.60	65.02	2.64	0.00	0.00	0.00	0.00	8.25
Demo-graphics	Avg. Number of Laborer	3.0	3.3	4.0	3.7	4.3	3.5	3.5	3.6
	Avg. Number of Member	4.7	5.0	5.0	4.8	5.6	4.7	4.5	5.3
Land Resources	Avg. Farmland Area per capita (mu)	2.9	0.6	1.4	1.9	1.7	1.2	0.9	0.6
	Avg. Plot Size (mu)	1.2	0.9	0.8	0.8	0.6	1	0.7	0.5
	Pct. Flat Area	100	83	100	100	76	100	100	67
Education	Pct. Households with Elementary (or below) Education	10.00	8.70	26.32	4.76	15.79	17.14	33.33	10.00
	Pct. Households with High School (or above) Education	25.00	43.48	31.58	57.14	47.37	48.57	24.24	25.00
Social Connection	Pct. Households with Government Contacts	34.78	35.00	21.74	5.26	14.29	47.37	17.14	21.21

Note: One mu is about 0.067hectares.

[1] The Spring Festival is a national holiday celebrating the lunar New Year. Most Chinese travel to their home towns to celebrate the holiday with family.

The surveys produced a comprehensive dataset about land use and livelihoods and other social-demographic information at the household and village levels (Table 4-2; Table 4-3; Figure 3-2)[2]. Information on land-use type and production was collected at the plot level and summarized to the household level. Demographic information, farmland endowment, and social connections (in terms of government contacts) were collected at the household level. Gender, age, education, and economic activities were collected for each household member. Total household income was summarized from the activities of members and total agricultural production. The data at the household level were then aggregated to the village level. Due to incomplete data for some major variables, only 193 surveyed households were included in the dataset for this analysis.

Table 4-2 Description of categorical variables at the household level

Variable Name	**Description**	**Frequency** (*n* = 193)
Flood Risk	1: in the very low risk zone	35
	2: in the low risk zone	23
	3: in the medium risk zone	42
	4: in the high risk zone	40
	5: in the very high risk zone	53
Close2City	1: village is close to its county capital	82
HaveBusinessIncome	1: household has income from business	17
	NA: data unavailable	16
HaveSalaryIncome	1: household has salary-based income	20
OwnTV	1: household owns TV set(s)	191
OwnRefrigerator	1: household owns refrigerator(s)	36
OwnAC	1: household owns air conditioner(s)	8
OwnComputer	1: household owns computer(s)	9
OwnMotor	1: household owns motor(s)	103
OwnCellPhone	1: household owns cell phone(s)	124
HouseStructure	1: mud	11
	2: brick	55
	3: concrete-steel	114
	4: others (mixed material)	10
	NA: data unavailable	3
HaveLoans	1: household has loans	84
HaveBankLoans	1: household has bank loans	10
HouseholdType	1: household has no children who are 6 years (or younger)	140
	2: household has children who are 6 years (or younger) and senior citizens who are 60 years (or older)	16
	3: household has children but no senior citizens	37
MoreFlatArea	1: percentage of flat farmland a household manages is above the average percentage of 85%	40

[2] The surveys were not successful in acquiring saving information. Many households were not willing to disclose this information, and the numbers given by some households were not very reliable.

	NA: data unavailable	20
Education5Levels	The highest degree that the household members received	
	0: illiterate	4
	1: elementary	28
	2: middle school	85
	3: high school	43
	4: college	33
Educaltion3Levels	1: elementary (or below)	32
	2: middle school	85
	3: high school (or above)	76
WithGovContacts	1: household has government contact(s)	46

Table 4-3 Description of quantitative variables at the household level

Variable Name	**Description**	**Min**	**Max**	**Median**	**Mean**	**SD**
Income per capita	Including income from all sources	0	32620	3778	4537	3824.7
Farming Income per capita	Including income from crop cultivation, forestry, livestock, fishing, aquaculture, and agricultural wages	0	15000.0	1028.0	1665.0	2102.0
Non-agricultural Wage per capita	Income from non-agricultural wage-based migration work	0	9400	1600	1973	2210.9
Salary-based Income per capita	Income from salary-based work	0	12000	0.0	545.6	1733.7
Business Income per capita	Income from business activities	0	20000	0.0	353.3	2161.9
Pct. Off-farm Income	Percentage of off-farm income, including non-agricultural wage, salary-based income and business income	0	100	67.94	55.97	38.10
Number of Wage-based Migration Jobs	Number of household members who do non-agricultural waged-based work	0	8	1	1.20	1.28
Number of Member	Total number of household members	2	10	5	5	1.68
Number of Laborer	Total number of household members who are older than 16 years and younger than 60 years	0	7	4	3.6	1.39
DependenceRatio (%)	Percentage of the number of children and senior citizens	0	100	0.0	15.31	19.85
PctLabor (%)	Percentage of the number of laborers	0	100	75.00	74.06	23.43
Farmland Area per capita (mu)	Total area of farmland per capita that a household manages	0	8.15	1.04	1.43	1.40
AvgPlotSize (mu)	Average size of plots	0	3.26	0.67	0.70	0.53
PctFlatArea (%)	Percentage of the farmland that is flat	0	100.00	100.00	86.61	27.69

Note: All income measures are in CNY.

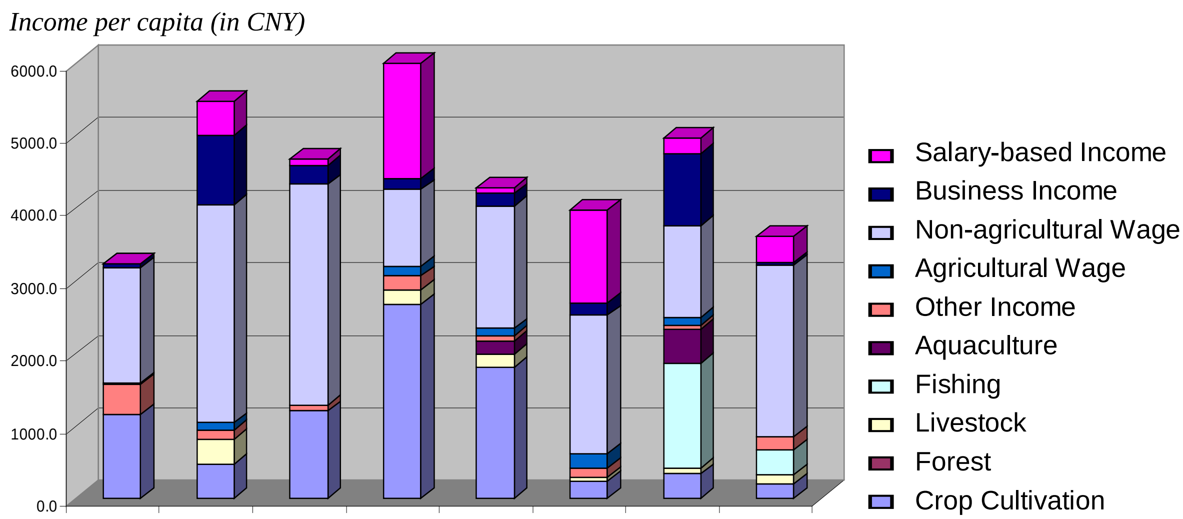


Figure 4-2 Livelihoods and income composition in the surveyed villages.

Interviews

As a follow-up to the surveys, I re-visited all 8 surveyed villages in July 2008 and conducted formal and informal interviews of 49 farmer households, 10 village leaders, and 10 local government officials (5 at the county level and 5 at the town level) (Table 4-1). I stayed with a household in each of three villages (ZJ, TJK and HXL), spending five to seven days with each, observing the daily life of villagers and engaging in informal conversations. I also interviewed some households that had not been surveyed previously when opportunities arose. I spent a half to a full day in each of the other five villages. Initially, I planned to stay in ZJQ too, a village near its county capital with significant income from growing vegetables. But their farmland was acquired by the county government for industrial development. So, instead, I spent one day in ZJYM, which is also close to its county capital and engages in some vegetable production. In each village, I visited the fields, in the company of a farmer or village leader, if possible, to familiarize myself with the natural environment and the quality of natural resources.

I followed Holstein and Gubrium's (1995) active interviewing approach. Instead of treating interviews as having a one-directional information flow from respondents to interviewer, I worked with respondents to construct a narrative together and interpret its meaning. For the formal interviews, I designed a set of questions with some central themes on land-use practices, land-use changes, other livelihood strategies, decision-making, crop cultivation, flood risk, life attitude, and living standard expectation, but was not limited by these questions. Before the interviews, I did a preliminary analysis of the survey data and found that some factors (e.g. education and government contacts) were associated with the income of households. During the interviews, I asked farmers for their perceptions about the impacts these factors had on their livelihoods and the livelihoods of other households. When interviewing farmers, I carried on the conversations to seek in-depth understanding and sometimes asked different questions to different farmers based on their answers and the characteristics of the households. All the interviews were digitally recorded.

To analyze interview data, I took an interpretivist's stance, interpreting the causal structure of the forces at work from individual experiences with the study subjects by studying what they do and how they think (Geertz 1973; Lincoln and Guba 1985). In practice, the methods that interpretive researchers use to interpret social facts vary greatly in the degree of formalization (Miles and Huberman 1994; Feldman 1995), from intuitive interpretation to highly formalized procedures like those based on grounded theory (Strauss and Corbin 1998). In this study, the purpose of qualitative analysis was mainly to complement and enhance the quantitative analysis, and therefore, I did not adopt a highly formalized approach, but rather used qualitative information from observations and interviews to develop in-depth understandings.

Measuring well-being of households

The quantitative analyses of well-being at the community, group, and household levels were based on the representation of well-being of households in development level, exposure, and sensitivity. I used income per capita to represent household development level. Low income is the central issue for development in less developed places. Income per capita often determines living conditions and captures most variations in living conditions between households (which I observed in the field and will demonstrate using the survey data throughout the analysis). Research shows that income per capita is a fairly good proxy for most aspects of development (Ray 1998).

I used the composition of income from different sources to represent sensitivity to flooding. Different income sources are affected by flooding differently. Climate sensitive incomes include farming income from crop cultivation, forestry, livestock, fishing and aquaculture, since they can be directly affected when floods occur. In contrast, off-farm incomes from non-agricultural wage-based work (wage-based migratory work), salary-based work, and business activities are usually not affected by flooding.

I used the flood-risk zone where a household is located to represent exposure. The flood-risk zones as defined in Table 3-1 characterize the environment with regard to flood hazards, and determine the degree to which a household is exposed to flooding.

Combining quantitative and qualitative data and methods

I combined quantitative survey data and qualitative information obtained from interviews and observations to examine the differences in livelihoods and development across surveyed villages. I compared their natural environments, locations, and other social characteristics to understand how these community-level factors affect the livelihoods of households. I combined interviews and observations to understand and interpret the results of statistical analyses of survey data, and I sometimes used survey data to confirm the understandings developed from interviews and observations. I used the interviews to understand the land-use and livelihood decision-making processes of households and demonstrate how the social and environmental factors at the community level and the policy and institutional context interacted with the characteristics of individual households to shape their livelihoods and well-being. The interviews also provided detailed information about crop-growth cycles and flood dynamics, which allowed me to examine how current agricultural practices are affected by flooding.

I examined variations in development level between surveyed households and identified three groups of households that exhibited extreme levels of income compared to others in the sample (extremely low and high income and extremely high development levels). I analyzed the livelihoods and characteristics of the households in each group to understand what made a household better or worse off. I also identified four major livelihood profiles among households and combined interviews and observations to explain which household characteristics and external conditions contribute to the success of these profiles.

I used statistical tests and linear regression models to analyze what factors were associated with the development level of most households. Two sets of statistical tests and regression models were performed separately that excluded (a) all extreme groups (defined above) and (b) the top two households. The potential explanatory variables for development level were grouped into seven categories: Environment, Farmland Resource, Education, Demographics, Social Connection, Finance, and Income Sources. They were chosen based on the theoretical understanding from the literatures on social vulnerability analysis, sustainable livelihoods analysis, and development economics, as well as my field observations. Because many of these variables were categorical, I also used the results of the statistical tests to exclude some variables from regression analyses and increase the degree of freedom of the regression models. Based on the difference tests of mean income per capita between households with five levels of education (from the original data collection), I re-categorized education into three levels: elementary (or below), middle school, and high school (or above) for regression analyses (Table 4-2).

Throughout the analyses, I also used the survey data to demonstrate that income per capita was correlated with the living conditions of households (in terms of house structure and ownership of air conditioners, refrigerators, computers, cell phones, and motorcycles) and to explore whether development at the household level was related to exposure.

Results

At the community level

Surveyed villages differed in mean income per capita (Figure 4-3), but the differences were not statistically significant due to large variations among households within villages (Figure 4-4).

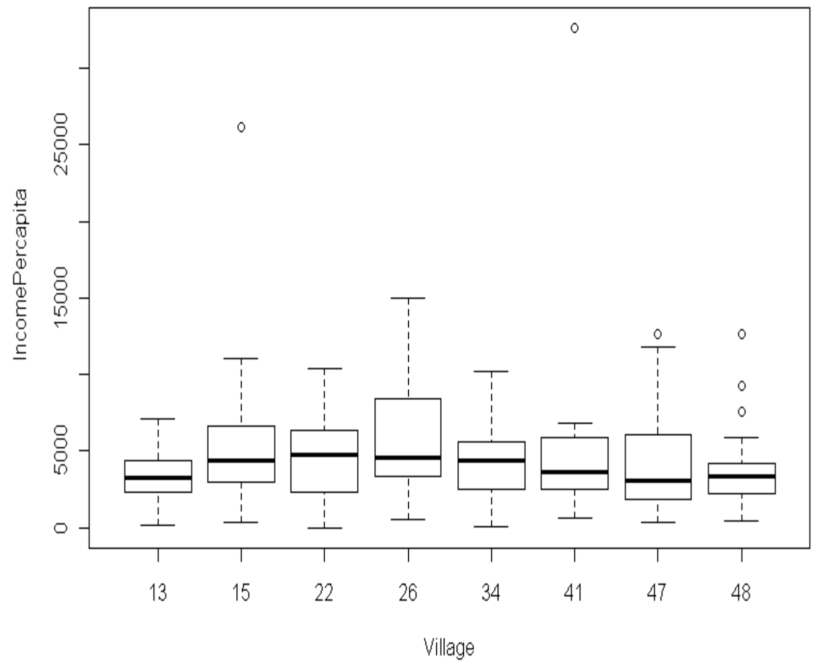


Figure 4-3 Income per capita across surveyed villages.

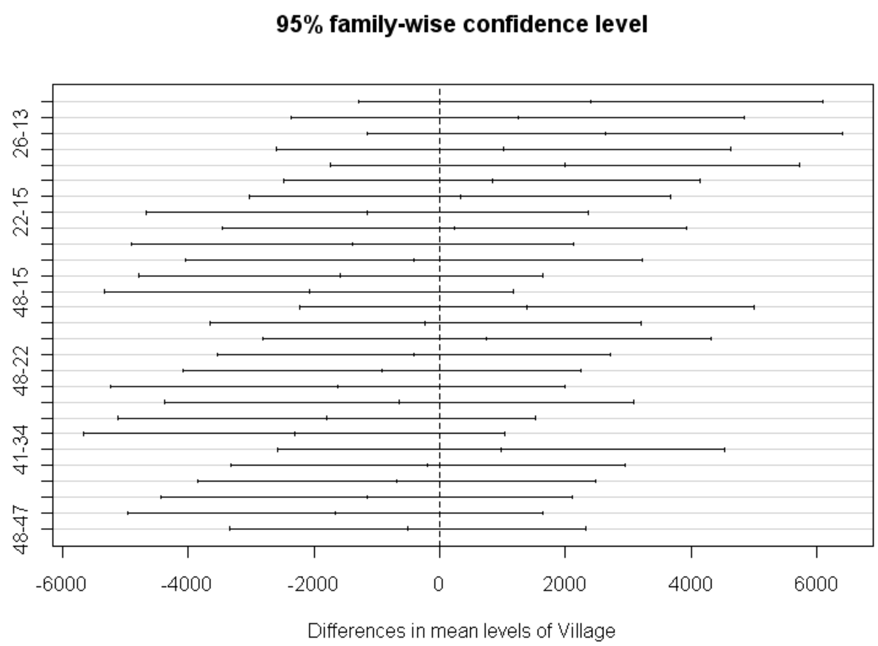


Figure 4-4 Difference test in mean income per capita across survey villages. The vertical axis represents every pair of surveyed villages.

However, some social and physical characteristics of a community provided certain advantages or disadvantages for the livelihoods of households. Being located near urban centers (like ZJQ and ZJYM) provided accessibility to high-return land-use (such as commercial vegetable production) and livestock options, as well as opportunities for seasonal off-farm work and salary-based jobs. Households located near urban centers could combine these options to make a good income without having to leave their homes. Villages endowed with special kinds of natural resources, such as mineral stones, could use and cash in these resources quickly (as TJK did at one time), but such places are few in number. Households in villages with rich and productive farmland, like ZJ, benefitted from combining good farming income with migration work, while households in farmland-poor villages, like HXL, relied largely on migratory work and faced the same challenges in seeking migratory work in the industrial sector. These are characteristics of communities over which policy makers have little control.

Social capital, especially the leadership of some capable farmers or households, can play an important role in shaping the livelihoods of all households in a village. Most villagers find migratory work through other people in their village (some through relatives). So the kind of migratory work they do, which largely determines their income, depends on the overall social connections between the village and the outside world. If a few households in a village do very well, what they do can inspire other households or create job opportunities for others. Even when government agencies choose villages for special development projects, they look at villagers' initiative because experience shows that a project is more likely to succeed if villagers demonstrate initiative and have the capacity to carry out the project. Strong leadership enhances the social capital of a village, while lack of leadership is often associated with a village's low development level, as well as low morale, which reinforces the hopelessness of a situation, as in SZT. In almost every successful development story, there is a visionary and capable leader who takes the interests of the village to heart and pulls the villagers together (Zhang and Chen, 2005). However, such leadership was lacking in the villages I visited.

Income per capita at the community level was not consistently correlated with exposure. Villages with lower flood risk do not all have higher mean income per capita, while villages with higher flood risk do not all have lower mean income per capita (Table

4-1). In fact, ZJQ and ZJYM had higher mean income per capita than all other villages, but they also had a higher flood risk than most villages.

Extreme-income groups

Based on the variations of income per capita among surveyed households (Figure 4-5), I identified three extreme groups of households. Group A had an extremely low development level (below 1,000CNY), Group B had an extremely high development level (above 25,000CNY), and Group C had a high development level (between 10,000CNY and 15,000CNY).

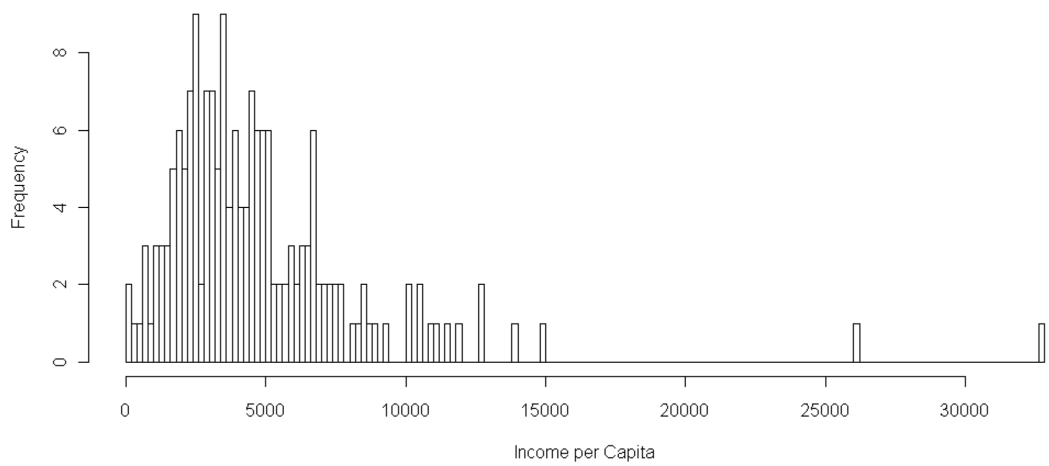


Figure 4-5 Distribution of income per capita among surveyed households.

The eight households in Group A shared several characteristics (Table 4-4). They all had a simple livelihood profile, relying completely on crop cultivation, and their income from crop cultivation was very low. They all had very low education levels, i.e., they were illiterate or had an elementary school education. Most of them did not have government contacts. Four of the households were comprised of an old couple who did not have the ability to do migratory work and barely got by growing subsistence crops[3]. Their living standard was also very low. They still lived in mud or brick houses, while most households had concrete-steel structured houses. They owned no air conditioners, refrigerators, cell phones, motorcycles, or computers. They were found across seven out

[3] Households comprised of an elderly couple that does not have sons to provide financial support are called Wu Bo Hu. They currently receive some monetary assistance from the government, but the amount is small and insufficient to have a comfortable life.

of eight surveyed villages, suggesting that extremely low development level at the household level was not correlated with location or flood risk.

Table 4-4 Group A: Households with an extremely low development level

Variable	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**
Village ID	22	34	47	26	48	26	15	13
Flood Risk	3	2	1	4	5	4	4	3
Close2City	1	0	0	1	0	1	1	1
Income per capita	0	50	300	500	738	800	855	750
Total Income	0	100	900	1000	1475	1600	3420	1500
Off-farm Income	0	0	0	0	0	0	0	0
Motor Number	0	0	0	0	0	0	0	1
Refrigerator Number	0	0	0	0	0	0	0	0
AC Number	0	0	0	0	0	0	0	0
Computer Number	0	0	0	0	0	0	0	0
Cell Phone Number	0	0	0	0	0	0	0	0
House Structure	1	2	2	2	2	1	2	2
Farmland Area (mu)	3.90	0.02	2.10	5.10	2.00	0.06	8.00	1.90
Number of Household Member	2	2	3	2	2	2	4	2
Number of Laborer	2	0	2	2	2	0	2	2
Household of an Elderly Couple	N	Y	N	Y	Y	Y	N	N
Education5Levels	0	0	1	1	1	0	1	1
Number of Government contacts	0	0	0	1	0	0	0	0

There were only two households in Group B, and both had significant income from business (Table 4-5), while the households in Group C had mixed livelihood profiles (Table 4-6). All households in Groups B and C enjoyed relatively good living conditions. The two households in Group B had air conditioners. Many of the households across both groups had motorcycles, cell phones, and concrete-steel structure houses. Half of them had refrigerators, and two owned computers. They were distributed across all surveyed villages, suggesting that a high development level at the household level was not correlated with location or flood risk.

Table 4-5 Group B: Households with an extremely high development level

Variable	H9	H10
Village ID	41	15
Flood Risk	5	4
Close2City	0	1
Income per capita	32625	26163
Total Income	130500	104650
Off-farm Income	84500	103000
Farming Income	46000	1650
Agricultural Wage	0	0
Non-agricultural Wage	0	0
Business Income	80000	75000
Salary-based Income	4500	28000
Motor Number	1	0
Refrigerator Number	1	1
AC Number	1	0
Computer Number	0	1
Cell Number	1	3
House Structure	3	3
Farmland Area (mu)	11.00	3.80
Number of Household Members	4	4
Number of Laborers	1	4
Education5Levels	2	4
Number of Government Contacts	5	0
Bank Loans (CNY)	100,000	0

Table 4-6 Group C: Households with a high development level

Variable	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22
Village ID	47	48	26	26	47	26	15	15	26	22	34	34
Flood Risk	1	5	4	4	1	4	4	4	4	3	2	2
Close2City	0	0	1	1	0	1	1	1	1	1	0	0
Income per Capita	12650	12625	15000	14000	11810	11520	11061	10805	10500	10418	10175	10050
Total Income	50600	50500	60000	42000	47240	57600	66364	75634	42000	41670	40700	40200
Off-farm Income	46000	48000	0	20000	46000	57600	56400	65200	12000	36000	15600	0
Farming Income	4600	2500	60000	22000	1240	0	9964	10434	30000	5670	25100	40200
Agricultural Wage	0	0	0	0	0	0	0	0	0	0	0	7000
Non-agricultural Wage	10000	0	0	20000	15000	9600	56400	29200	0	36000	0	0
Business Income	0	0	0	0	0	0	0	36000	0	0	15600	0
Salary-based Income	36000	48000	0	0	31000	48000	0	0	12000	0	0	0
Motor Number	0	1	1	3	1	0	0	2	1	1	1	1
Refrigerator Number	1	0	1	1	0	1	0	0	1	0	0	0
AC Number	0	0	0	0	0	0	0	0	0	0	0	0
Computer Number	0	0	0	0	0	2	0	0	2	0	0	0
Cell Number	2	3	0	1	2	5	3	3	3	1	1	0
House Structure	3	3	3	3	3	3	3	4	3	2	3	2
Farmland Area (mu)	5.70	3.87	8.00	3.60	3.50	0.00	10.40	13.50	10.7	4.80	6.30	32.60
Number of Member	4	4	4	3	4	5	6	7	4	4	4	4
Number of Laborer	4	4	2	2	4	5	5	7	3	4	2	2
Education5Levels	3	4	3	2	4	4	4	3	3	2	4	2
Number of Government Contacts	0	0	0	1	2	1	0	0	1	0	2	1

The livelihoods of the households in Group B and C suggested that each of the following livelihood profiles can lead to a high level of development: (i) diversified near-home livelihood profile, (ii) business-oriented high-return livelihood profile, (iii) farming-based livelihood profile, and (iv) combined migratory work and farming livelihood profile. Certain household characteristics and some external conditions are important for the success of these profiles (Table 4-7).

Table 4-7 Household characteristics important for the success of different livelihood profiles

Livelihood Profile Type	Sub-type	Total Labor	Edu-cation	Risk Taking	Hard Working	Social Status &Connection	External Conditions
I. Diversified near-home profile	A member is a village leader		*	*		***	
	No member is a village leader		*	*		*	Location near urban centers
II. Business-oriented high-return profile	Business as the major income		*	***		***	Location near urban centers
III. Farming-based profile	High-cash-value crop cultivation			*	***		Location near urban centers
	Large-scale grain production			*	***	**	Good farmland resources
IV. Combined migratory work and farming profile	Salary-based work as the major income source	**	***			*	
	Wage-based migration work as the major income source	***	**				

Note: The number of * indicates the degree of importance.

There were two common types of households successful in creating a diversified near-home livelihood profile: those in villages near urban centers and those whose members are village leaders. While households that live near urban centers can take advantage of their location, village leaders have some other advantages in establishing diversified livelihoods. They usually have better connections with local government officials. These connections and their status in the village are important components in acquiring use-right contracts for special resources that are often scarce in a village (such as fish ponds) and obtaining business loans. Village leaders are also better informed about the outside world, and therefore, more aware of business opportunities.

Among the wealthiest households were those that experienced business success. These households were few and appear to have a special kind of capability. My interviews revealed that willingness to take risk was a common characteristic. All farmers understood that high economic returns involve high risks, and many shared successful risk taker stories. But very few were willing or able to take such risks. Social connections were important for finding business opportunities and obtaining investment capital. Most households did not initially have investment capital. They borrowed money from friends, relatives, or banks to start a business. As a special form of social connections, government contacts sometimes offered business opportunities directly, helped obtain bank loans, and gave better access to information. The survey data illustrated that larger proportions of the households that had business income and bank loans had government contacts than those that did not have such contacts (Table 4-8). These business savvy households did not necessarily possess very high levels of education, and there was no significant difference in business income between education levels (Table 4-9). These households did not necessarily have significant labor either because they could and often do hire laborers.

Table 4-8 Government contacts and other variables

Number of Households	**Category**	**Without Government Contacts**	**With Government Contacts**	**Pct. Households with Government Contacts**
HaveBankLoans	N	140	43	23.50
	Y	7	3	30.00
HaveBusinessIncome	N	137	41	23.03
	Y	10	5	33.33
HaveSalaryIncome	N	133	40	23.12
	Y	14	6	30.00
Number of Non-agricultural Wage-based Jobs	0	56	19	25.33
	>=1	147	27	22.88
	>=2	118	15	12.71

Table 4-9 Education levels and different kinds of income

Difference in Mean (*p*-value of significance test)	**Education Levels**			**Interpretation**
	Between 1 and 2	Between 1 and 3	Between 2 and 3	
Income per capita	2226.45 Y(0.02)	3508.31 Y(0.00008)	1281.86 N(0.09)	Households with an elementary (or below) education level have a lower income per capita on average.
Farming Income per capita	734.40 N(0.21)	763.54 N(0.20)	29.14 N(0.99)	No difference in farming income between education levels.
Non-agricultural Wage per capita	1137.71 Y(0.04)	1189.08 Y(0.04)	51.37 Y(0.99)	Households with an elementary (or below) education level have a lower non-agricultural wage on average.

Business Income per capita	257.33 N(0.84)	362.27 N(0.73)	104.93 N(0.95)	No difference in business income between education levels.
Salary-based Income per capita	-30.50 N(0.99)	938.88 Y(0.02)	969.38 Y(0.0009)	Households with a high school (or above) education level have a higher salary-based income on average.

Households that had a farming-based livelihood profile were commonly hard working in the sense that farmers have to use great physical strength and tolerate bad weather conditions because farming in the villages is still accomplished using human labor. While being located near an urban center facilitates vegetable cultivation, living in a place with rich farmland is helpful for the success of farming households because it facilitates large-scale rice production. There were commercial vegetable production success stories in places far from urban centers, but this scenario takes extraordinary leadership and effort. To form a scale of production large enough, farmland over large areas, often including a whole village, town or even county, would need to be converted to vegetable fields. Sales channels in cities and transportation would have to be arranged and coordinated for all the producers. Some farmers also managed large areas of rice production in villages other than their own. For these farmers, social connections were even more critical to contract land-use rights, and they took a higher risk because land-use-right contracts in rural China are privately negotiated and are usually renewed yearly.

Education and labor were most important for the success of combined migratory work and farming livelihood profiles. Salary-based jobs were usually more stable and better paid than wage-based migratory work, but also required higher education levels. Migrant workers with low levels of education often did wage-based jobs that were hard or involved poor working environments. Households with high school (or above) education levels on average had higher salary-based income, whereas households with elementary (or below) education levels had lower income from wage-based migratory work (Table 4-9). The total labor of a household determined its total production. Because wages for migratory work do not vary significantly, when more members participated in this work, more income was accrued. Government contacts sometimes helped secure salary-based jobs. A larger proportion of households that had salary-based income had government contacts (Table 4-8). But, as the number of household members doing waged-based migratory work increased, the proportion of households with government contacts decreased (Table 4-8). Indeed, those households that relied on waged-based migratory work as the major income source usually did not have other better livelihood options that government contacts would help secure.

While certain combinations of household characteristics (in education, labor, risk taking, hard working, and social connections) and external conditions (in location and farmland resources) contributed to the success of various livelihood profiles in Group B and C, their negative combination resulted in the crop-cultivation-dependent livelihood profile and extremely low development levels of households in group A. The characteristics of a household also interacted with each other to reinforce the household's livelihoods and characteristics over time. Households that had accumulated investment capital during the initial period of economic reforms were now more willing to take risks and were able to further diversify their economic activities for continuous growth. But when a household was poor, it tended to be more cautious about borrowing money to invest in new high-return livelihoods, was less likely to obtain loans, and therefore, more likely to maintain traditional low-return livelihoods, thus falling into a poverty trap. Another situation in which households fell into a poverty trap involved illness of a key household member. In such cases, a household not only lost productive labor, but also incurred significant debt from medical care, which made it impossible to begin new high-return livelihoods. Without external interventions, it was difficult for these households to break the poverty cycle.

Moderate-income households

For most households, income per capita was significantly associated with how many of its members performed wage-based migratory work and whether a household had salary-based income (Table 4-10; Table 4-11). This suggests that migratory work was important for explaining the variations in income per capita between most households. The importance of salary-based income became larger when only the top two households were excluded ($p=0.0004$ compared to $p=0.04$ when all income extremes were excluded), and the importance of wage-based migratory work was reduced (Table 4-11). This indicates that wage-based migratory work contributes more to the income per capita variations between moderate-income households than salary-based income. In fact, most households relied more on wage-based migratory work (Table 4-3). The fact that farmland area per capita was also a significant factor (Table 4-11) suggests that farming was still an important component of the livelihoods for most households, and farmland resources contributed to some between-household variations in income per capita. Indeed, the livelihoods of most households involved some combination of salary-based work, wage-based migratory work, and agricultural work, i.e., the majority of the households had livelihood profile type IV.

Table 4-10 Summary of the statistical tests

Dependent Variables (*p*-value)	**Income per capita**		**Included in Regression Models**
	Excluding All Special Groups	Excluding Top Two Households	
Flood Risk	N (0.63)	N (0.16)	N
Close2City	N (0.19)	N (0.19)	N
Education3Levels	Y (0.004)	Y (5.50e-07)	Y
HouseholdType	Y (0.04)	Y (0.02)	Y
MoreFlatArea	N (0.11)	N (0.16)	N
HaveLoans	N (0.86)	N (0.52)	N
HaveBankLoans	N (0.89)	N (0.83)	N
HaveBusinessIncome	N (0.85)	N (0.44)	N
HaveSalaryIncome	N (0.35)	Y (0.01)	Y
WithGovContacts	N (0.06)	Y (0.01)	Y

Table 4-11 Linear regression models

Variable Category	**Independent Variables**	**Excluding All Extreme Groups**		**Excluding Top Two Households**	
		Coefficient	*p*-value	Coefficient	*p*-value
Education	Education3Levels 2	651.95	0.14	1233.29	0.03 *
	Education3Levels 3	1110.34	0.018 *	2056.44	0.0006 ***
Demographics	HouseholdType 2	-476.69	0.47	-236.10	0.77
	HouseholdType 3	-701.27	0.12	-1043.69	0.06@
	DependenceRatio	0.23	0.98	-10.52	0.34
	PctLabor	8.91	0.19	9.99	0.23
Land Resources	Farm Area per capita	266.35	0.06 @	272.18	0.14
	AvgPlotSize	-401.16	0.26	-105.82	0.82
Income Sources	Number of Wage-based Migration Jobs	551.63	0.0005***	601.23	0.002 **
	HaveSalaryIncome	1232.55	0.04*	2536.09	0.0004 ***
Social Connection	WithGovContacts	597.11	0.099@	920.62	0.04 *
Intercept		2062.31	0.0005***	1434.70	0.05@
Adjusted R-squared		0.1987		0.2819	

Note: Significant codes 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘@’ 0.1

Education level and government contacts were significantly associated with income per capita for most households (Table 4-10; Table 4-11) because they were important for migratory work, as demonstrated by the group analysis. When excluding all extreme groups, the government contacts variable became less important, suggesting that variation in government contacts among moderate-income households was small relative to variation that included the more extreme-income groups. Most moderate-income households did not have government contacts (Table 4-2). For most households, having children but no elderly people in the home (Household Type 3) was negatively associated with income per capita (Table 4-11). Households that have children but do not have elderly grandparents to care for them results in parents having to stay on the farm, while many households only have elderly people and children at home when both male and female adults do migratory work outside of the region. The variations in percentage of labor and the dependence ratio between moderate-income households were probably not large due to the family planning policy in China.

Most households had a livelihood profile IV but executed it to varying degrees of success, depending on their characteristics in education, demographic structure, social connections, and their farmland resources. Households with a livelihood profile IV in the high-income group (Group C) generally achieved higher incomes than other households because they had better education and/or more labor and/or government contacts.

Also consistent with the group analysis, location and flood risk were not associated with income per capita, and income per capita was mostly correlated with other aspects of living conditions (Table 4-10; Table 4-12). Households that had computers, air conditioners, or mud houses were few (Table 4-2), and I, therefore, did not test for differences in mean income per capita. The survey data suggest that the few households that had air conditioners or computers had relatively high incomes, and the few households that still lived in mud houses had relatively low incomes. Motorcycles were becoming a common transportation tool, and many households could afford them.

Table 4-12 Statistical tests of mean income per capita against other variables representing living conditions

Difference in Mean (*p*-value of significance test)	**House Structure** (between brick and concrete-steel structure)	**Own Cell Phone**	**Own Refrigerator**	**Own Motor**
Excluding All Special Groups	766.66 Y (0.04)	704.76 Y (0.02)	1248.39 Y (0.008)	372.89 N (0.23)
Excluding Top Two Households	1553.77 Y (0.0009)	1476.90 Y (0.0006)	2237.71 Y (0.001)	1041.94 Y (0.01)

Discussion

Household decision making and rural development

Farmer households are economic agents, and their livelihood profiles reflect an attempt to increase their economic benefits in an increasingly free-market economy under some internal and external constraints. A household's land-use and livelihood decision-making process is to first determine its feasible options, and then allocate its labor and farmland to the feasible options, giving higher priorities to feasible options that have higher economic returns (Figure 4-6; Figure 4-7). The characteristics of a household interact with the characteristics of the community, the social, economical, and political context, and the natural environment to determine its livelihood profile and the extent of its success in executing the profile.

The natural environment provides natural capital for household livelihoods. It can enable certain high-return livelihoods by providing particular natural resources. It also determines household's quality of farmland resources and potential crop outputs. But the natural environment's services are fixed based on the location. In the process of urbanization, the development of rural household livelihoods are affected and can be significantly shaped by social, economic, and institutional factors and forces in the human system, especially the development dynamics of the agricultural and industrial sectors.

Institutions, policies, and processes at the macro level have a significant impact on the livelihoods of rural households in China. The policy reforms that began in the late 1970s have dramatically changed the livelihoods of rural households by shifting production decisions from collectives to individual households and making migratory work feasible. In general, development policies affect rural households' job opportunities and wage levels in the industrial sector. In the agricultural sector, subsidy policies can increase the economic return of crop cultivation, while land policies define the land-use rights of farmer households and how they acquire land-use rights. Land policies are particularly important

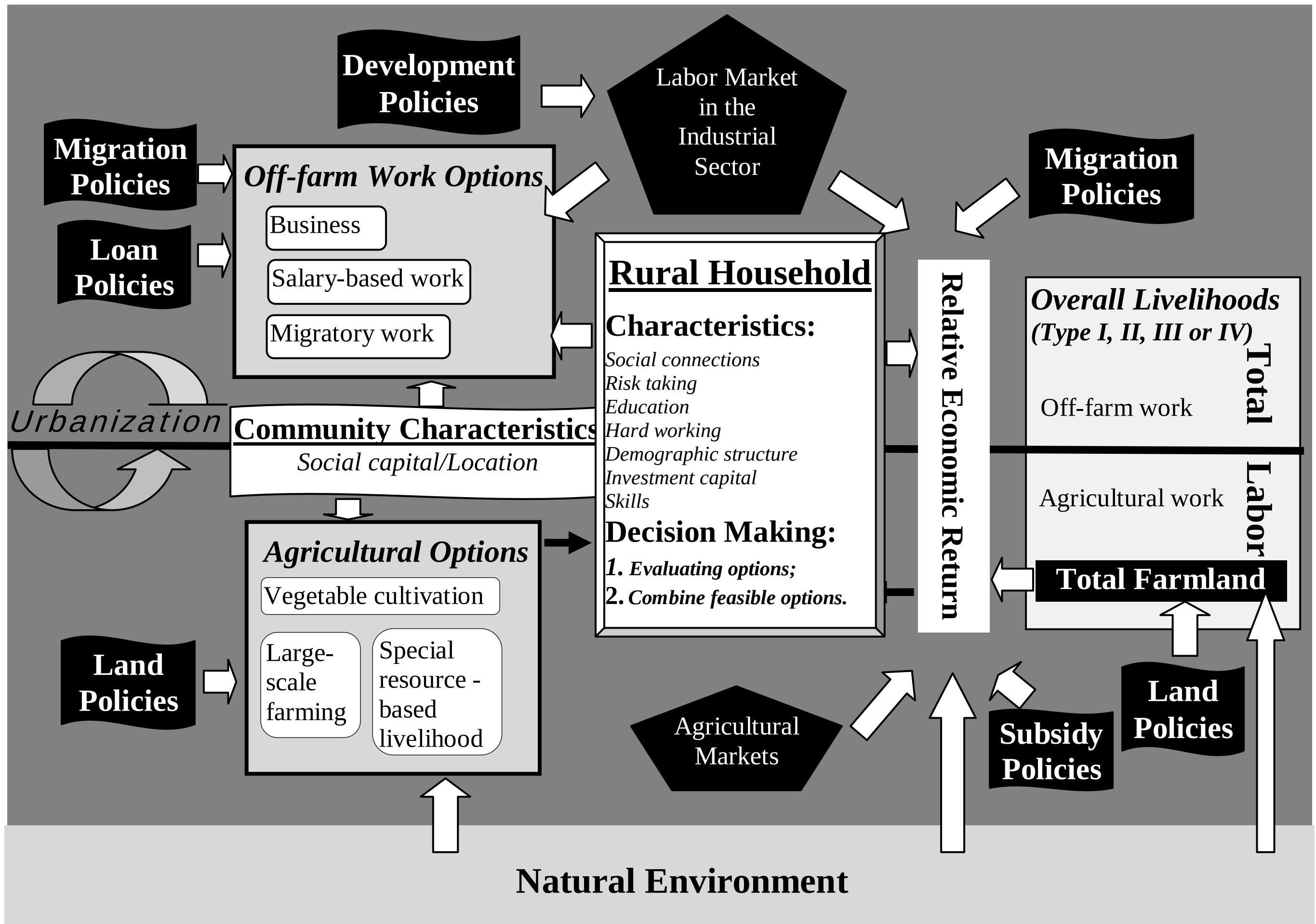


Figure 4-6 Multi-level and multi-source causes of well-being and household decision-making.

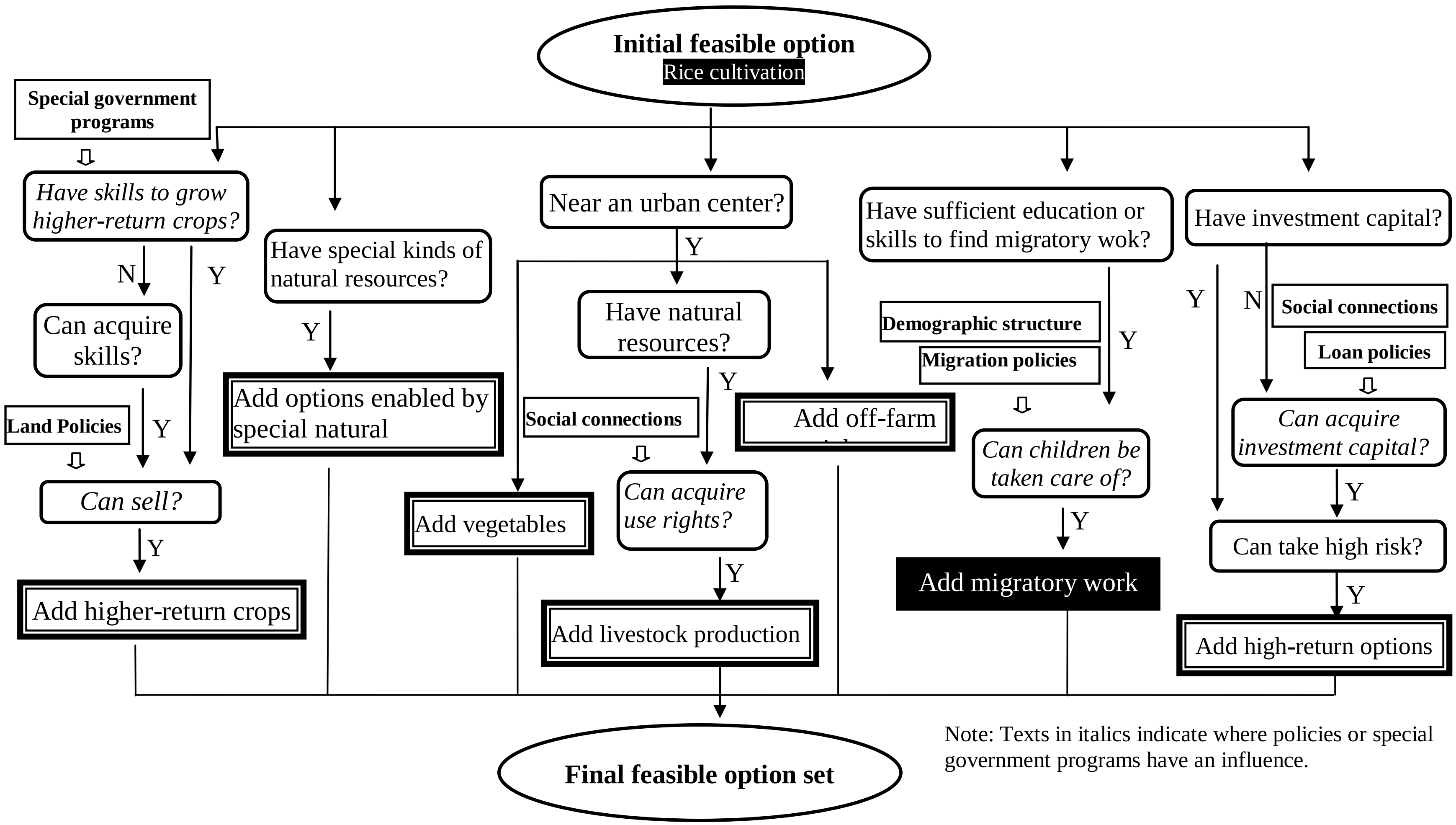


Figure 4-7 Constraints and option evaluation.

because they can shape farming scales in rural China. The current small farmland holdings of households, resulting primarily from the land allocation systems established by Household Responsibility System, are now a significant constraint for agricultural productivity and rural development (see appendix). Migration policies regarding the social security and benefits of migrant workers affect their decisions about whether to settle permanently in cities and how to deal with their land-use rights in the countryside. Because of the differentiation of urban and rural Hukou, migrant workers do not have the same rights and benefits as the resident urban population. They regard their farmland in the countryside as their ultimate security and hold on to it even if they do well in cities. Combined with the insecurity of land-use-right contracts, this situation leads to farmland in the countryside being carelessly managed or, in some places, left fallow. Many households identified lacking investment capital as a major constraint for their livelihoods, and loan policies affect who can obtain loans and how, especially low-interest government loans.

The livelihoods of individual households are affected by some community characteristics. While being located near an urban center enlarges the feasible option set, irrigation facilities and road infrastructure in a community provide physical capital for its households. A well-functioning irrigation system improves agricultural output by modifying natural conditions of the environment. Good road access facilitates market access and information flow[4], which is important for farmers to get oriented in a market economy. More importantly, a village's social capital, in terms of leadership and overall quality of social connections with the outside world, has a significant impact on the livelihoods of all households in that village.

The feasible option set and the livelihoods of a household, however, are mostly determined by household characteristics. Though the natural environment and some factors at the community level can provide advantages or disadvantages for the household livelihood, individual households are not totally confined by them and have room to exploit opportunities in a market economy, as demonstrated by the group analysis. At the household level, human capital and social capital are essential because they do not only directly shape the feasible option set and determine how successfully a household carries

[4] An ongoing rural development program is extending road access to every village in rural China.

out its livelihoods, but also affect how successfully a household acquires farmland-use rights and accumulates financial capital, with physical capital defined by the characteristics of the community and natural capital largely determined by the environment. The development of household livelihoods is also path dependent, and the outcomes of a household's livelihood choices reinforce its characteristics and capabilities over time.

The number of households that have achieved high levels of development with a livelihood profile I, II or III is not large. As a result of constraints on feasible options, most rural households end up with a livelihood profile IV (Figure 4-7). In interviews, farmers often referred to the Chinese term "Men Lu." "Men" means door and "Lu" means road in Chinese. The closest interpretation of Men Lu in English is feasible option. These farmers explained their bad situations resulted from a lack of Men Lu, and they attributed the success of some other households to their possessing Men Lu. These unsuccessful farmers have done what they can. Every household member who can find migratory work is doing migratory work (often far away from home), and those who cannot (mostly elderly people and some women) stay on the farm and cultivate limited farmland. Constrained by their education levels and skills, migrants typically seek work in the labor-intensive industrial sector, and their wages remain low because the market is flooded with a large rural population seeking migratory work. This confirms Lewis's (1954) theory that the expansion of a "capitalist" sector at an early stage of development only draws more workers from the "subsistence sector," and the capitalists do not need to raise wages due to "unlimited supplies of labor." In addition, the economic return from crop cultivation is generally low, in part because of limited farmland area. People cannot alter traditional crop types to high-cash-value crops because they are constrained by the small farmland area (and the disincentive of short-term leases of land-use rights). These are the very reasons that rural income is low and difficult to increase. Rural development in China is essentially about these households[5].

[5] The land-use and livelihood decision-making of farmer households in PLR is not fundamentally different from households in more economically developed places. Entrepreneurs are small in number, and they appear to have special capabilities, of which risk taking is an important quality. As most humans do, farmer households in PLR seek better living conditions and try to improve their living situations. With a history of being poor and now exposed to new opportunities in a market economy, they are more eager to seek economic benefits, and therefore, are more driven by economic gains than preferences. But they are

To break this undesirable resilience (i.e., rural income and agricultural production remain low despite various efforts to increase them) of rural development in China, a comprehensive set of development policies and broader policy reforms are necessary. Policies need to address rural development as an integral part of overall development in China, especially aimed at lifting constraints and assisting rural households in building robust livelihoods via different paths. Rural-to-urban migration, home-based development, and large-scale farming are all important for future rural development and for transforming China into a developed country.

While continuing to promote the development of the industrial sector (the engine of overall economic growth) to further absorb the surplus of rural labor and increase migratory work wages, appropriate migration policies are needed to encourage those rural households that prosper in cities to actually settle in cities, so they no longer hold their farmland-use rights as security. Training and education programs that aim to improve migrant workers' competitiveness and preparedness are necessary in helping migrant workers secure better-paid jobs and increasing overall workforce productivity.

Further land-use rights reforms are needed to facilitate more efficient farmland allocation in rural China, which will increase farming income and help the agricultural sector grow in tandem with the industrial sector. Through large-scale farming, farmer households that remain in the countryside will be able to generate an income similar to off-farm work (see appendix). In 2008, the seventeenth planning session of the Chinese Central Government Committee announced some guidelines on rural development (Xinhua, 2008), which allow and further encourage farmers to circulate land-use rights through exchange, subcontracting, leasing and renting, transfer, and joint stock partnership. The new policy also calls for the establishment of legal markets to facilitate

constrained by their education levels and skills. These citizens in rural China are also constrained by a low level of development at the national level, and their livelihoods depend more on the overall growth of the industrial sector in the dynamic process of urbanization. The role of preferences in shaping the livelihoods of households is small and mainly reflected in the choice between migratory work and agricultural work. Most young people do not like to work on the farm because farming involves bad weather conditions and great physical strength (many of them do not know how to farm), while middle-aged people would prefer to stay on the farm if they had other high-return livelihoods near the village. But because migratory work, in general, has a higher return on labor, they usually opt for migratory work anyway.

land-use-right circulation. The implementation of the new policy and its effects remain to be seen.

Near-farm high-return livelihood options need to be expanded to more farmer households by promoting home-based industry. Home-based industries may focus on activities that suit and take advantage of the natural environment and integrate agriculture and local culture into the overall development plan. Government assistance in identifying options, organizing people, and providing financial support at the initial period are helpful[6]. Such projects could serve as seeds and place an emphasis on building leadership among households. Combining a bottom-up approach with top-down support is promising: one farmer can lead other farmers, one village can lead other villages, and one town can lead other towns. With a large rural population and limited farmland, this local urbanization process is important for China's rural development because existing cities, facing various social and environmental problems for further growth, have limited capacities to absorb rural labor.

Additional programs are necessary to increase the overall well-being of rural households. A better social security and welfare system, including a more comprehensive medical-care system, is needed for the entire rural population[7]. This is also an effective way to share the fruits of economic reforms with the rural population, whose interests have previously been compromised for urban development in the past because of national policies. Special programs are needed to help households with extremely low levels of development, and such programs should target household characteristics. Special programs are also needed to help households in places with poor natural resources and high exposure to natural hazards find and secure urban livelihoods and undertake a smooth out-migration process.

Other "soft" aspects of well-being need to be improved as well. Across the villages, playing Majiang for money is popular. During a period of fast development, people can easily fall into seeking short-term economic benefits and miss an integrated and

[6] The government agencies have been actively working with farmer households to create Farmer Household Associations to encourage and help farmers to adopt new agricultural or other livelihood options. Through a farmer household association, households can also provide credit for each other to obtain bank loans.

7 The current health care system in rural areas has limited benefits, particularly regarding severe illness.

meaningful life. But in the long-term, this will hurt China's population. Though what is a meaningful life needs further articulation, healthy forms of entertainment are helpful.

Because human capital is essential for increasing capability at the household level, education programs are helpful and needed to empower the rural population for the long-term. Such programs can make use of the existing TV networks and fast-growing cell-phone networks.

Sensitivity to flooding, equity, and fairness

The livelihoods of most households are not greatly affected by flooding. Income diversity exists across all surveyed villages (Table 4-1; Figure 4-2), and on average, more than half of the total income of households is from off-farm sources (Table 4-3). Among the four major livelihood profiles, farming-based livelihoods appear to be more sensitive to flooding. However, commercial vegetable production is usually practiced in places near urban centers. Large-scale rice production is often found in places with good and rich farmland, and these places are usually major agricultural production bases. Because major urban centers and major agricultural bases in PLR are protected by crucial levees that are well built and maintained by the government, the households that practice these types of livelihoods are not likely to be greatly affected by flooding. Households with extremely low levels of development, however, are found across locations, and their crop-cultivation-dependent livelihoods are highly sensitive to flooding. Therefore, the poor are also most affected by flooding.

Current agricultural practices appear to be sensitive to flooding. Severe floods, which usually occur between July and September, can affect early rice harvesting, late rice planting, and one-season rice and cotton growing. Rice production in particular can be heavily damaged when severe floods occur in July because the early rice harvest can be reduced or totally lost, and the late rice planting season can be missed if flood waters remain for lengthy periods.

However, the degree to which the agricultural system is affected by flooding varies across locations. Those villages with good and rich farmland, again, are usually major rice production bases and are protected by crucial levees. The sensitivity of their agricultural production is very low. Agricultural production in the high flood-risk zone is sensitive to flooding. Based on the regional assessment, 21.6% of farmland in PLR is in the high flood-risk zone, i.e., at risk of being flooded more than once every ten years. Those villages with poor farmland resources are usually protected by low-quality levees (built by the local people), and their agricultural production is, therefore, highly sensitive to flooding.

In places that have a high flood risk, the government can incorporate flood-impact mitigation into development by promoting new land-use practices that can increase land profitability and reduce flood damage. Further encouraging larger-scale farming would help relax the constraint of small farmland holdings and make these new land-use practices feasible for farmer households.

With the agriculture system also highly sensitive to flooding, places with poor farmland resources have an additional development disadvantage. Providing additional assistance to households in such places in establishing new livelihoods in cities is an effective way to address the natural environment’s inherent unfairness that is further exasperated by the social system. The government can also help develop new land-use practices that particularly suit the characteristics of the natural environment in such places to utilize the marginal land and further increase rural households’ farming income.

Conclusions

My analysis at the community level suggested that, though several characteristics of communities can provide advantages or disadvantages for the livelihoods of individual households, the mean development levels are not significantly different across villages because the between-household variations are large in the same village. Each village has its unique characteristics, indicating both constraints and opportunities for development and suggesting different development pathways and the need for different policy interventions. Those villages endowed with special kinds of natural resources need to look ahead and invest their accumulated capital in developing other livelihoods so as to achieve sustained development. Those villages with good farmland resources need to further increase land-use efficiency to fully realize the potential of their farmland. For those locations with poor natural resources and high exposure (such places are often poor too), migration may be a long-term solution. This migration is happening slowly because the livelihoods of households in such villages rely largely and increasingly on migratory work. Households in such places may take advantage of the urbanization process to build up robust livelihoods in cities.

The analyses of extreme-income groups and moderate-income households suggest that a household's development level is largely determined by its livelihood profile and how successfully it executes that profile. Four major types of livelihood profiles existed among surveyed households: (i) diversified near-home livelihood profile, (ii) business-oriented livelihood profile, (iii) farming-based livelihood profile, and (iv) migration work and farming combined livelihood profile. Each of these profiles can lead to high levels of development if a household possesses certain characteristics, some of which are facilitated by external conditions.

The analysis of the household land-use and livelihood decision-making processes demonstrates that the livelihood profile a household has and to the degree to which it is successful in executing that profile is largely determined by the household's characteristics (mainly its human and social capital), influenced by some social and physical factors at the community level (leadership, location and natural resources), and greatly affected by institutions, policies, and the urbanization process at the macro level. Most rural households have few feasible options, rely on migratory work as the major income source, and are unable to raise their incomes to a higher level because they are constrained by small farmland area, some of their own characteristics, the overall development of the industrial sector, and the large supply of rural labor.

To effectively promote rural development and increase the overall well-being of rural households in China, three paths are important: rural-to-urban migration, home-based industry, and large-scale farming. The government needs to implement appropriate policies and carry out further reforms to facilitate rural development via these paths. A better welfare system and education programs are needed to serve the entire rural population. Special programs are necessary to address inequity and social and environmental unfairness. These policies and programs need to complement one other.

The livelihoods of most farmer households in PLR are not greatly affected by flooding, but the poor are affected the most. Current agricultural practices appear sensitive to flooding, but the degree to which the agricultural system is affected by flooding varies village to village. Villages with good and rich farmland are major rice production bases which are usually protected by crucial levees, and therefore, the sensitivity of their agricultural production is low. About one fifth of the farmland in PLR is exposed to high flood risk, where agricultural production is sensitive to flooding. Villages with poor farmland resources are usually protected by low-quality levees), and their agricultural production is, therefore, highly sensitive to flooding. These villages have an additional development disadvantage. The government can combine flood-impact-mitigation efforts with development projects in various ways to better promote the well-being of rural households. The development levels of individual households in PLR are not associated with (or constrained by) flood risk. The central issue of sustainability in PLR and rural China is persistently low levels of development.

A major limitation of this study involves the limited number and geographical coverage of surveys and interviews. By understanding the decision-making of rural households in the dynamic process of urbanization and complemented with other studies of rural development in China, I hope the findings from this study apply to rural development in general.

References

Adger, W. N., Kelly, P. M,, Winkels, A., Huy, L. Q. and Locke, C. (2002) Migration, Remittances, livelihood Trajectories and social Resilience. *AMBIO: A Journal of the Human Environment* 31(4), 358–66.

Adger, W. N., Brooks, N., Bentham, G., Agnew, M. and Eriksen, S. (2004) *New Indicators of Vulnerability and Adaptive Capacity*. Tyndall Center for Climate Change Research Technical Paper no. 7, January.

Allison, E. H. (2005) The fisheries sector, livelihoods and poverty reduction in eastern and southern Africa. In: Rural Livelihoods and Poverty Reduction Policies (eds.) Ellis, F. and Freeman, H. A. Routledge, London, 256–73.

Ashley, C. and Carney, D. (1999) *Sustainable Livelihoods: Lessons from Early Experience*. Department for International Development, London.

Banerjee, A. and Iyer, L. (2005) History institutions and economic performance: the legacy of colonial land tenure systems in India. American Economic Review, 95(4), 1190–1213.

Banerjee, A., Cole, S., Duflo, E. and Linden, L. (2007) Remedying education: evidence from two randomized experiments in India. *Quarterly Journal of econo*mics, 122(3), 1235–1264.

Bardham, P. and Udry, C. (1999) *Development Microeconomics*. Oxford University Press.

Bebbington, A. (1999) Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. *World Development* 27, 2021–44.

Bhandari, B. S. and Grant, M. (2007) Analysis of livelihood security: A case study in the Kali-Khola watershed of Nepal. *Journal of Environmental Management* 85, 17–26.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B. (1994) *At Risk: Natural Hazards, People's Vulnerability and Disasters.* Routledge, London.

Brooks, N., Adger, N. W. and Kelly, M. P. (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, 15, 151–63.

Card, D. (2001) Estimating the return to schooling: progress on some persistent econometric problems. *Econometrica* 69(5), 1127–1160.

Cutter, S. L., Boruff, B. J. and Shirley, W. L. (2003) Social vulnerability to environmental hazards. *Social Science Quarterly* 84,242–261.

Deaton, A. (1997) *The Analysis of Household Surveys: a microeconometric approach to development policy*. World Bank Publications.

De Mel, S., McKenzie, D. and Woodruff, C. (2008) Returns to capital in microenterprises: evidence from a field experiment. *The Quarterly Journal of Economics* 123 (4), 1329–1372.

DFID (1999, 2000 and 200) *Sustainable Livelihoods Guidance Sheets.* Available at http://www.eldis.org/.

Duflo, E. (2003) Grandmothers and granddaughters: old age pensions and intra-household allocation in South Africa. *World Bank Economic Review*, 17(1), 1–25.

Dwyer, A., Zoppou, C., Nielsen, O., Day, S. and Roberts, S. (2004) Quantifying social vulnerability: a methodology for identifying those at risk to natural hazards. *Geoscience Australia*. Available at http://www.ga.gov.au.

Eades, J. (2003) Ethnographies of the vanishing? Global images and local realities among the aborigenes of Taiwan, 1600-2000. In: *Globalization in Southeast Asia: Local, National and Transnational Perspectives* (eds.) Yamashita, S. and Eades, J. Berghahn Books, New York, 226–252.

Eakin, H. (2003) The Social Vulnerability of Irrigated Vegetable Farming Households in Central Puebla. *Journal of Environment and Development.* 12 (4), 414–429.

Eakin, H. (2005) Institutional change, climate risk, and rural vulnerability: cases from central Mexico. *World Development* 33(11), 1923–1938.

Eakin, H. and Luers, A. (2006) Assessing the vulnerability of social-environmental Systems. *Annual Review of Environment and Resources* 31, 365–394.

Eriksen, S. H., Brown, K. and Kelly, P. M. (2005) *The dynamics of vulnerability: locating coping strategies in Kenya and Tansanya. The Geographical Journal* 171(4), 287–305.

Ellis, F. and Mdoe, N. (2003). Livelihoods and rural poverty reduction in Tanzania. *World Development* 31(8), 1367–1384.

Farmar-Bowers, Q. and Lane, R. (2009) Understanding farmers' strategic decision-making processes and the implications for biodiversity conservation policy. *Journal of Environmental Management* 90, 1135–1144.

Feldman, M. (1995) *Strategies for Interpreting Qualitative Data*. Sage Publications, Thousand Oaks, CA.

Foster, A. and Rosenzweig, M. (1996) Learning by doing and learning from others: human capital and technical change in agriculture. *Journal of Political Economy* 104, 1176–1209.

Jalan, J. and Ravallion, M. (2002) Geographic poverty traps? A micro model of consumption growth in rural China. *Journal of Applied Econometrics* 17(4), 319–346.

James, C. S. (1985) *Weapons of the Weak: Everyday Forms of Peasant Resistance* Yale University Press.

Jellinek, L. (1997) Displaced by modernity: the saga of a Jakarta street-traders family from the 1940s to the 1990s. In: *Cities in the Developing World: Issues, Theory, and Policy* (ed.) Gugler, J., Oxford University Press, USA, 139–155.

Geertz, C. (1973) *The Interpretation of Cultures*. Basic Books, New York, NY.

Hewitt, K. (ed.) (1983) *Interpretations of Calamity*. Allen Unwin, London.

Holstein, J. A. and Gubrium, J. F. (1995) *The Active Interview*. Sage Publications, Thousand Oaks, CA.

Kremer, M. (1993) The O-Ring theory of economic development. *The Quarterly Journal of Economics* 108(3), 551–575.

Lewis, W. A. (1954) Economic development with unlimited supplies of labor. *Manchester School of Economic and Social Studies*, 22, 139–91.

Lincoln, Y. S. and Guba, E. G. (1985) *Naturalistic Inquiry*. Sage Publications, Newbury Park, CA.

Ma, D., Chen, J. Zhang, W., Zheng, L. and Liu, Y. (2007) Farmers' vulnerability to flood risk. *Journal of Geographical Sciences* 17(3), 269–284.

Miles, M. and Huberman, A. M. (1994) *Qualitative Data Analysis: A Sourcebook of New Methods* (2nd Edition). Sage Publications, Beverly Hills, CA.

Neely, C., Sutherland, K. and Johnson, J. (2005) Do sustainable livelihoods approaches have a positive impact on the rural poor? A look at twelve case studies. Livelihoods support programme, working paper 16. Food and Agriculture Organization, Rome.

Ray, D. (1998) *Development Economics*. Princeton University Press, Princeton, New Jersey.

Ribot, J. C., Najam, A. and Watson, G. (1996) Climate variation, vulnerability and sustainable development in the semiarid tropics. In: *Climate Variability, Climate Change and Social Vulnerability in the Semi–arid Tropics* (eds.) Ribot J. C., Magalhaes, A. R. and Panagides, S. Cambridge Univ. Press, Cambridge, UK, 13–51.

Ribot, J. C. (2009). Vulnerability does not just fall from the Sky: toward multi-scale pro-poor climate policy. In: Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World (eds.) Mearns, R. and Norton A. The World Bank, Washington, DC.

Psacharopoulos, G. (1985) Returns to education: A further international update and implications. *Journal of Human Resources* 20(4), 583–604.

Rygel, L., O'sullivan, D. and Yarnal, B. (2006) A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country. *Mitigation and Adaptation Strategies for Global Change* 11,741–764.

Schultz, T. P. (2004) Evidence of returns to schooling in Africa from household surveys: monitoring and restructuring the market for education. *Journal of African Economies*, 13(02), ii95–ii148.

Seeley, J., Biraro, S., Shafer, L. A., Nasirumbi, P., Fostzer, S., Whitworth, J. and Grosskurth, H. (2008) Using in-depth qualitative data to enhance our understanding of quantitative results regarding the impact of HIV and AIDS on households in rural Uganda. *Social Science & Medicine* 67, 1434–1446.

Sen, A. (1981) *Poverty and Famines: An Essay on Entitlement and Deprivation.* Oxford Univ. Press, Oxford.

Sen, A. and Dreze, J. (eds.) (1990) *The Political Economy of Hunger.* Clarendo, Oxford, UK.

Steimann, B. (2005) *Livelihood Strategies in North-West Pakistan.* Results from the Sustainable Livelihoods Survey 2004, North-West Frontier Province (Pakistan) IP6 Working Paper No. 5 Available at http://nccr-pakistan.org/publications_pdf/Gender/IP6_WP5.pdf

Strauss, A. and Corbin, J. (1998) *Basics of Qualitative Research, Techniques and Procedures for Developing Grounded Theory*. Sage Publications, Thousand Oaks, CA.

Strauss, J. and Thomas, D. (1995) Human resources: empirical modeling of household and family decisions. In: Handbook of Development economics (Volume 3) (eds.) Behrman, J. and Srinivasan, T.N. North Holland, Amsterdam, 1885–2023.

Susan, E. (1977) *The Poverty of Revolution: The State and the Urban Poor in Mexico.* Princeton University Press.

Swift, J. (1989) Why are rural people vulnerable to famine? *IDS Bulletin* 20, 8–15.

Udry, C. (1996). Gender, agricultural production, and the theory of the household. *Journal of Political Economy* 104(5), 1010–1045.

Vincent, K. (2004) Creating an index of social vulnerability to climate change for Africa. *Working Paper Series at Tyndall Centre for Climate Change Research*. Available at http://www.tyndall.ac.uk.

Watts, M. J. (1987) Drought, environment and food security: some reflections on peasants, pastoralists and commoditization in dryland West Africa. In: *Drought and Hunger in Africa* (ed.) Glantz, M. H. Cambridge University Press, Cambridge, 171–212.

Watts, M. J. and Bohle, H. G. (1993) The space of vulnerability: the causal structure of hunger and famine. *Progress in Human Geography* 17, 43–68.

Xinhua, the State News Agency (2008) Announcement: The decisions of the Central Government of China on some important issues regarding promoting rural development reforms. *Xinhua News* 19 October.

Chapter V

Future Rural Development: Insights from an Agent-Based Model

Introduction

This chapter presents an agent-based model about future rural development in PLR. Building on insights from the analyses of land use (see appendix) and household well-being (Chapter IV), I used the model to (i) quantitatively assess how various components of CHES (the natural environment, market mechanism, and policy setting) may affect rural development (the development level of the agricultural system and the well-being of rural households) and (ii) to explore if an alternative policy could better shape the system for a sustainable future.

The analyses of land use and household well-being suggest:

(i) Farmer households are economic agents who attempt to increase their economic benefits in an increasingly free-market economy.

(ii) Most rural households, constrained by small farmland holdings, some of their own characteristics, and the overall development of the industrial sector, have few feasible options, rely on migratory work as the major income source, and are unable to raise their incomes to a higher level.

(iii) In the process of urbanization, the livelihoods and well-being of rural households are affected significantly by national policies (especially land polices), and the development dynamics of the agricultural and industrial sectors are at the center of the "three issues" of rural development as outlined in Chapter II.

(iv) The effects of the current rice cultivation subsidization policy on rural development are small. Farmland area is a lever that may be exploited by government policies to promote agricultural production and rural income. And, to be effective, policies need to be sensitive to environmental and social variations.

(v) The fact that land-use-right contracts are signed for short terms has contributed to the reluctance of farmer households to rent in larger areas for farming operations.

The analyses of land use and household well-being, however, do not provide quantitative assessments of farmland resource constraints and current policy effectiveness. It also remains a question whether the performance of the private land rental market plays a role in hindering larger-scale farming operations. Various studies (Luo 1988; Yang 1997; Rao 2000; Sonntag et al. 2005; Qu, Heerink and Xing 2006; Deininger and Jin 2007) have argued for the important role of well-functioning rental markets for land-use rights and the need to stimulate these rental markets in rural China. Yet no information regarding the current private market's performance is available in the literature.

Based on this previous work, it is reasonable to conclude that a policy subsidizing households to rent out their land-use rights for long terms may facilitate larger-scale farming operations in rural areas. Many Chinese scholars have argued that further land-use policy reform is necessary to meet the significant challenges of rural development in China (Li and Li 1989; Wei 1989; Wang 1990; Qu 1991; Chi et al. 1999; Chi 2000; He and Huang 2001; Yang 2001; Dong 2008), but these scholars have different opinions about how to reform land policies around the issue of land rights. While some scholars argue that farmers should be given permanent land-use rights and allowed to sell or use their land-use rights as collateral, others are concerned that this could lead to social instability if farmers sell their land-use rights for short-term gains. Given that the issue of land rights is a sensitive topic in China, and that farmers have long been attached to the farmland that also serves as their ultimate livelihood security, granting farmer households longer-term land-use rights and encouraging them to trade their land-use rights for longer terms should be an effective and politically acceptable approach. This proposed approach conforms to the guidelines on rural development announced by the Chinese government in 2008 (Xinhua, 2008) that reaffirm the land-use rights of rural households and continue to encourage rural households to exchange land-use rights through various mechanisms.

Specifically, I developed an agent-based model to develop understandings about the following questions:

(i) How much are farmer households in PLR constrained by the availability and quality of farmland resources?

(ii) Is the current private market for land-use rights sufficient for matching the demand and supply of land-use rights?

(iii) How effective is the current policy of subsidizing rice cultivation in promoting agricultural production and increasing rural income?

(iv) Can an alternative policy that subsidizes long-term renters of land-use rights induce the system to reach a more desirable state, and, if so, how might policies need to vary across places?

I used survey data from three villages, which represent different kinds of farmland endowments in amount and quality, as empirical reference to calibrate and validate the model. First, I compared relative values of several outcome variables (average rental price for land-use rights, percentage of off-farm income, percentage of farmland in two-season rice, and percentage of cultivated area) from model experiments with the empirical data in these villages. Then, I compared modeled land-use changes (in terms of farmland allocation between two-season rice and one-season rice) in these villages with the observed historical changes (predominantly involving the conversion of two-season rice to one-season rice). Because the land-rental market is an important component in the model, I examined whether its modeled behavior conforms to the economic theory by looking at the relationships between average rental prices for land-use rights and other variables that can affect it (amount of farmland, average wage for migratory work, and productivity of farmland), thereby further increasing the confidence level about the model.

To assess the effect of farmland constraints on household behaviors, I used the model to simulate a hypothetical scenario in which there are unlimited farmland resources, and households can acquire land-use rights at no cost. I measured how much land farmer households would farm in each place and other outcome variables (percentage of off-farm income, average total income, and percentage of labor on migration work), and compared them with those generated from simulations of real scenarios in each place.

To assess private market performance under current conditions, I examined the overall trading success rates from model experiments under some realistic levels of effort farmer households put into finding trading partners in each place. The trading success rate was measured by total traded area of land-use rights divided by the smaller of supplied or demanded area for land-use rights.

To evaluate and explore the effects of existing and potential policies (to address the third and fourth questions), I examined (i) changes in the state of the system, (ii) economic efficiency, (iii) fairness (in the sense that households with poor farmland endowments deserve more compensation), and (iv) trajectory of the system, which reveals the dynamics of the processes and indicates the potential for future growth. I used multiple outcome variables to represent the state of the system: (i) total agricultural production (overall development of the agricultural sector), (ii) total income (well-being of rural households), (iii) percentage of cultivated area (extent of farmland utilization), (iv) percentage of farmland in two-season rice (intensity of farmland utilization), and (iv) percentage of farmland managed by the top 10 households (scale of farming operations). I used two measures to evaluate the economic efficiency of policies: (i) increase of total agricultural production per unit cost, and (ii) increase of total income per unit cost.

The modeled system

Figure 5-1 describes the components of the modeled system, including farmer households, their actions and interactions, and feedback between their individual decision-making processes and the collective outcomes of their decisions and actions.

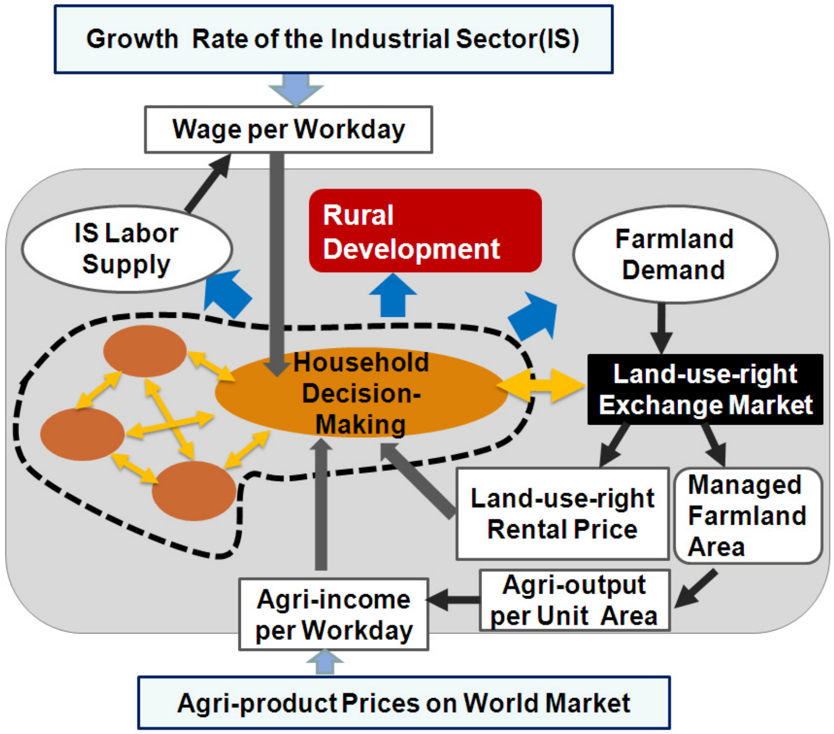


Figure 5-1 Modeled system: boundary, interactions and feedback. The objects inside the dashed line represent household agents and their information networks. The objects inside the gray box are modeled as endogenous entities. The objects outside the box are exogenous but important to the decisions of households. The solid gray arrows illustrate what factors at the system level affect individual household decision-making. The thick blue arrows illustrate what collective outcomes result from the actions and interactions of individual households. The black arrows indicate relationships between variables at the system level. The double-headed yellow arrows represent information flow and interactions between households on the market.

The model simulates farmer households that have a livelihood profile IV, as identified in Chapter IV (i.e., migratory work combined with crop cultivation). These households constitute the majority of rural households in PLR, and the central issue of rural development is about the livelihoods and well-being of these households. Each household makes decisions about the amount of labor spent on agricultural work and migratory work in the industrial sector. The household then allocates farmland plots to one of two crops: one-season rice and two-season rice. The households interact with each other through a land-rental market and sometimes exchange information, such as prices for land-use rights. They carry out their livelihoods with different degrees of success, mostly determined by the availability of labor, capabilities of doing 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. The wages and prices can also be influenced by the decisions/actions of households. For example, the wages for migratory work are kept low because of a large supply of rural labor to the industrial sector. But they are not determined by the decisions/actions of the households at the village level, so are treated exogenously. Also, because I intend to explore, at the current development level of the industrial sector, how the government could better promote rural development, wages for migratory work, and prices for rice are not modeled endogenously but treated as relevant entities whose values are set by model parameters.

Two kinds of feedback between individual decisions and actions and the global state of the system are modeled: (i) the decisions and actions of households collectively determine total farmland demand, which affects rental prices for land-use rights on a local market, and therefore, subsequent decision making of households; (ii) total farmland demand also affects the farmland area each household can obtain, which affects scales of farming scales and agricultural productivity, and, ultimately, the decision-making of households.

I made several assumptions about the system in the model. First, farmers can always find migratory work if they want to work in cities (with varying levels of wage). Second, farmer households do not hire labor. Third, rice yields increase as the area of farmland a household manages increases because of increased efforts, possible improvements in irrigation conditions, machinery usage, and other innovations. I discuss the implications and the effects of these assumptions on model results in the section on the model's limitations.

Empirical data

I used empirical data obtained from surveys, interviews, and field observations in three villages as reference data to represent places with good, average, and poor farmland resources. 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 on rural development in different kinds of places regarding the biophysical environment. The three villages V1, V2, and V3 (Table 5-1) were chosen from the eight surveyed villages, and they correspond to TJK, FJ and ZJ respectively in the previous analyses.

Table 5-1 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 environmental endowments.

Characteristics		**V1**	**V2**	**V2**
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 (The major system stopped working. Only a small pump can be used to get water from a pond, but households need to pay an hourly fee for usage.)	Poor (Destroyed. Can rent privately owned pumps with an hourly fee to get water from a pond.)	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	Rental Price for Land-Use Rights (YUAN per mu)	About 50 (Small plots on hills are free)	Between 100 and 150	About 300
	Pct. Off-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: 1mu is about 0.067hectares.

The rice yields used for setting model parameters in V1 and V2 are not strictly from the surveys but represent the average yields, taking into consideration the variable weather conditions over years and the overall qualities of plots. In V1, two-season rice is only cultivated in a few plots near a pond, and the yields reported by the two households in the survey (750kg) do not represent the average yield. In V1, there are also unfertile plots on hills (about 17% of its total farmland) where rice cultivation is even less productive, and other less-demanding crops, such as peanuts, are cultivated. In both V1 and V2, the yields of rice, especially two-season rice, are significantly affected by the annual weather conditions due to the poor quality irrigation system. Farmer households usually opt not to rent pumps to irrigate their fields due to cost, and the pumps can only get water to plots within a certain distance of the ponds. In fact, some households in V1 chose to grow early rice (over one-season rice) because water availability is more of a problem on hilly terrain, and early rice can benefit from the rainy season. Farmers in V1 only harvested about 200kg of one-season rice per mu during the period when I interviewed them, while normally it could be about 450kg (from the survey). In V2, the past yield of two-season rice was about 750kg per mu (according to two interviewed households). In both villages, interviewed farmer households complained about the negative effect the poor irrigation system had on rice yields.

The empirical data relevant to model validation were not to be compared strictly with model experiments in each village for several reasons. First, the surveys' percentage values of two-season rice were not expected to be the same as those generated from model experiments. In each village, there are low-lying areas that are prone to rainfall in the rainy season, and where only one-season rice is planted. In V1 and V2, there is also some cotton production. Second, in both V1 and V2 (and across places in PLR), a major change in land use involves two-season rice being replaced by one-season rice after migratory work became widely available in the 1980s, but exactly how much farmland area planted with two-season rice has been converted to one-season rice in V1 and V2 is information that is not available. In V3, there might be a small change in the proportion of two-season rice because of migratory work, but the empirical data is not sufficient to determine whether one-season rice was only planted in low-lying areas or was also planted in some areas where two-season rice was previously planted. Third, the percentage of off-farm income from the surveys was not exactly the same by definition as that in the model. Off-farm income from the surveys includes income from all non-agricultural activities, some of which (e.g., business) were not modeled. Fourth, the rental prices for land-use rights in each village were gathered from interviews and may not present the whole range of values because of the relatively small number of households I asked for this information.

The empirical data were used to test the model's ability to generate differences in several outcome variables at the village level between places that have different farmland endowments. The important general facts that guided the model validation (the differences between the three villages) are: (i) in V1 and V2, there was a reduction in two-season rice since economic reforms began, and farmer households now typically grow one-season rice; in V3, there was no obvious change in the proportion between one-season rice and two-season rice, and two-season rice still dominates; (ii) the average rental price for land-use rights was in increasing order from V1 to V2 and V3; (iii) the proportion of income from migratory work was in decreasing order from V1 to V2 and V3; (iv) a small portion of farmland was left fallow in V1, while farmland was largely cultivated in V2 and V3.

The three villages also represent different situations that are associated with different rice yields, and I used these differences to calibrate the rice-yield functions with increasing scales of farming operations as explained in detail in the next section.

Model design and implementation

Agents: farmer households

Farmer households 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 5-2). They know the costs and labor needed per unit area associated with crop 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 crop cultivation, as well as experiences with the rental market for land-use rights.

Table 5-2 Endowments and attributes of households in the model: description and range

Endowment/ Attribute	Description	Distribution Among Households	Lower Bound	Higher Bound
Initial Wealth	An initial endowment of wealth (in YUAN)	Uniform	5,000	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	Determines the maximum wage members of a household get paid for migratory work (in YUAN per work day). Used as a multiplier to the average wage for migratory work set by model parameter *AvgWageInitial.* 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. The differentiation between members in migratory work capability is modeled by a migratory work efficiency function (described in detail in the section of migratory work efficiency function).	Normal (1.0, 0.2)	0.5	1.5
Agricultural Work Capability	Determines the yields of rice per mu a household obtains. Used as a multiplier to 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	Represents how many other households a household maintains good relations with. Affects the success of negotiating land-use-right rental contracts. For instance, a social capability of 0.8 can be interpreted as a household having good relations with 80% of the households in the village, and it fails 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.

The decision-making process of a household agent is described with the following pseudo code.

```
{
    Form its expectation on the rental price for land-use rights per unit area;
    Estimate income from agricultural work per unit area by doing the following:
    {
        If (it did agricultural work in the previous year)
            Calculate income per unit area using data from the previous year;
        Else
        {
            Update its yields from past experiences with new information from other
                households;
            Calculate income per unit area based on newly estimated yields;
        }
    }
    Estimate wage for migratory work per work day by doing the following:
    {
        If (it did migratory work in the previous year)
            Calculate wage for migratory work based on data from the previous year;
        Else
            Update wage from past experiences with new information from other households;
    }
    Form a few plans, compare their economic returns;
    Choose the plan that produces the largest return;
    Compute its need for renting in/out farmland;
    If (long-term rental is an option)
            Make decision on whether to rent in/out for the long term;
}
```

At each step, which can be interpreted as a year, but not in a strict sense[1], a household forms several land-use and livelihood plans and chooses the one that it predicts will generate the best economic return. A plan includes: the amount of labor to spend on migratory work, total farmland area it intends to manage--accounting for its own farmland and any farmland it rents either in or out, and the allocation of the managed farmland area to one-season rice and two-season rice. At the beginning, with no experience, a household begins by making a random plan. It chooses the percentage of

---

1 Having a step in the model represent exactly one year will take extraordinary calibration efforts, and there is no way to verify the calibration because we only have empirical data at one point in time. To make one step represent exactly a year would likely mean overlooking other more, important aspects of the system. I demonstrate later that the time step in the model reasonably approximates one year.

labor to spend on migratory work and the percentage of farmland area to plant one-season rice on randomly from a uniform distribution [0,100].

To form new plans and evaluate plans, a household computes how much money it made per day from migratory work in the previous year and how much income it generated per unit area from crop cultivation. The household forms expectations about the rental price for land-use rights and uses it to calculate the economic returns of the plans that involve exchanging land-use rights on the market. The household uses information from other households that are randomly selected to update its past performance in crop cultivation or estimate average wages for migratory work if it has cultivated crops or done migratory work in the past three years.

To form rental price expectations for land-use rights, the household adjusts the market price it observed in the previous year based on its own trading performance if the household intended to trade (or actually traded) last year. The performance is represented by a successful trading rate: the percentage of actual traded area relative to the total area intended for trade. If the successful trading rate was between 50% and 90% in the previous year, the household forms its price expectation by increasing or decreasing the observed trading price in the previous year, depending on whether the household intended to rent in or out, respectively, by one tenth of the estimated farming income from a unit area. If the rate was below 50%, the household makes a larger adjustment by combining two tenths of its estimated farming income from a unit area and the average price of some other households whose successful trading rate was not lower than 80% in the previous year. If the rate was greater than or equal to 90%, and some fallowed plots were observed in the previous year, the household lowers its expected rental price accordingly. If the household did not have trading experiences in the previous year, it estimates the rental price using the best information it can collect from other households with a successful trading rate of at least 60%. The household begins with randomly selected households (6 each time) and looks at those with a successful trading rate of at least 90% and lowers the rate by 10% each time, assuming households with the specified rate last time cannot be identified. If the expected rental price is greater than its estimated farming income from a unit area, the household only uses the price to evaluate plans, and it does not ultimately rent in any plots. In the first step, when households have no prior knowledge of rental price, they pick a random number from a uniform distribution [0, 1, 0.1] and use it to compute the rental price as a proportion of the expected income from growing one area unit of rice.

To form new land-use and livelihood plans, a household makes adjustments based on its plan from the previous year. With a probability of 90%, the household increases labor in the more profitable activity (migratory or agricultural work) by a random amount and decreases the labor in the less profitable activity, based on its performances over the past three years. If the difference in economic returns from migratory and agricultural work over the past three years on average was smaller than 0.1YUAN per work day, the household randomly chooses the amounts of labor for migratory and agricultural work. If the household has only worked in one sector in the past three years, it puts a random amount of labor (between 0 and 50 percent of the total labor amount) to the activity that it has not done in the past three years with a probability of 40%. Then, the area of farmland the household can manage is calculated by comparing the labor available in agricultural work to the labor needed for crop cultivation per unit area. Five crop allocation plans are formed and evaluated based on the relative economic returns from one-season rice and two-season rice in the previous year. The household increases the proportion of the planting area of the crop that provided better return by a random amount (between 0 and the proportion of area planted in the other crop). If the household only grew one crop in the last year, it assigns (with a probability of 20%) a random amount of farmland area (between 0 and 50 percent) to the other crop. If the total farmland area it intends to cultivate is smaller than 0.5mu, the plan is finalized by allocating all labor to migratory work.

The evaluation of an alternative policy for land-use contract rentals requires that the model include subsidies for long-term land-use contracts. Under this scenario, a household looks at its economic activities and performances in the previous years to decide whether it will enter into long-term contracts for renting land (in or out). If the household intends to rent out land-use rights this year, it looks back five years. If more than 70% of its income came from migratory work in all five of those years with no more than a one-year exception, and the income it would receive from renting out its land-use rights for the long term (20 steps in the model), plus any subsidy for renting, is greater than what the household would receive otherwise (e.g., if it rents yearly), it decides to go with long-term rental contracts. If the household intends to rent its land-use rights this year and had intended to manage more farmland than the initially contracted area in each of the past three years, it decides to rent in land-use rights for the long term. The land-use rights rented in for the long term cannot be rented out again for the long term and still receive a subsidy, but they can be rented out yearly. To receive the subsidy on long-term contracts, a household must rent out the use rights for all its initially contracted area.

After choosing a land-use and livelihood plan, a household first rents in/out land-use rights on the private market if the plan involves this activity. If the household has decided to rent in/out through long-term contracts, it first tries to do so, and then attempts to rent in/out yearly if it is not fully successful in long-term trading. After trading on the land-rental market, it updates its plan based on the trading result. It then realizes the plan, and updates its total wealth and its records on incomes from migratory work and the two crops, labor amount spent on these activities, intended farmland area to manage, actual farmland area managed, the proportion of the two crops, yields of crops, and land-use-right rental prices.

Private rental market for land-use rights

The private market for land-use rights was implemented as a two-round exchange process. When long-term contracts are not an option, the households that intend to rent in begin first. They visit a number of random households, with the number specified by a model parameter *NumHouseholdTrade* (described in Table 5-3). If a chosen household does not have a good social relationship with the household seeking to rent, with the chance determined by the social capability of the initiating household, no contract is made. If the price offered by the household that intends to rent 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 that intends to rent in, the deal is done at the average of the two prices. After the first round of exchange, if some households that intend to rent out still have farmland left unrented, they each randomly choose and visit several other households to negotiate rental contracts. Again, if the chosen household does not have a good social relationship, no contract is made. If the price asked by the household that intends to rent out is less than the price offered by the chosen household, 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 are an option, households 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 that intends to rent out is less than the price offered by the chosen household, the deal is done at the price asked. Otherwise, if the price asked by the household that intends to rent out is no more than 5% of the price offered, the deal is done at the average of the two prices. Then, the households that intend to rent in land-use rights through long-term contracts and whose needs have not been fully met sample households looking to rent in. After two rounds of exchange through long-term contracts, the households update their remaining demands on yearly contracts. Those households whose needs for long-term rental are not met, and those households that have decided to rent in/out land-use rights yearly perform another two rounds of exchange and make yearly contracts.

Major model parameters

Table 5-3 describes the major model parameters. The default values are used unless specified otherwise in the model experiments.

Table 5-3 Model parameters: description and default value

Parameter Group	Parameter Name	Description	Unit	Default Value	Experimental Values
Agricultural Product 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	
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 (new policy)
Scenario	*Hypo-scenario*	when set true, the model simulates a hypothetical scenario in which there are unlimited farmland resources, and households can acquire land-use rights at no cost.		false	set true only for the experiments on farmland constraint
Household Behavior	*AvgNumPlans*	average number of land-use and livelihood plans households form and evaluate		5	
	NumHousehold Trade	number of households a household visits to negotiate land-use-right contracts		6	6, 8,10 used for the experiments on market efficiency
	SocialEffects	whether social relations affect the success of land-use-right rental deals (when set false, this social effect is ignored)		true	set false for some experiments on market efficiency
Village-Specific	*AverageArea*	average area of farmland per household	mu		
	Irrigation System	condition of the collective irrigation system	1: Good 0: Poor	Set as described in Table 5-1 for the three villages respectively.	
	AvgAgriOutput 1sRiceInitial	average yield of one-season rice	kg per mu		
	AvgAgriOutput 2sRiceInitial	average yield of two-season rice	kg per mu		

Model initialization

At the beginning of each model run, 100 households 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 is assigned an initial amount of wealth, labor, farmland area, and capabilities as described in Table 5-2.

Each household is first assigned land-use rights for an area of farmland that is proportional to that household's labor amount. However, land-use rights are currently distributed inequitably because of demographic changes since they were first assigned to individual households in the late 1970s. For example, households with sons have to divide the initially contracted farmland when the sons get married, while the labor available per unit farmland is decreased after a household's daughters get married. Therefore, the contracted areas are adjusted in the model by randomly choosing either 1/2, 1/3 or 1/4 of farmland assigned to a random selection of half of the households and transferring this proportion of the initially assigned area to another household that is selected randomly from all households.

Migratory work efficiency function

I used an efficiency function to capture the different levels of labor quality for a household's migratory work. The idea, based on observations from my field work, is that the first people from the household to enter the 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 form and parameters of the function were chosen based on empirical data, using the following equation: $Y = (1-x)^p$ where p = ½ when x <= 60%; p = 1 when x > 60%; x is the percentage of labor a household 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 <= 60% (1/3 and1/4) were also tested. When p was set to ½, the outcome variables at the village level from the model experiments were closer to the empirical data in the three villages than other values of p.

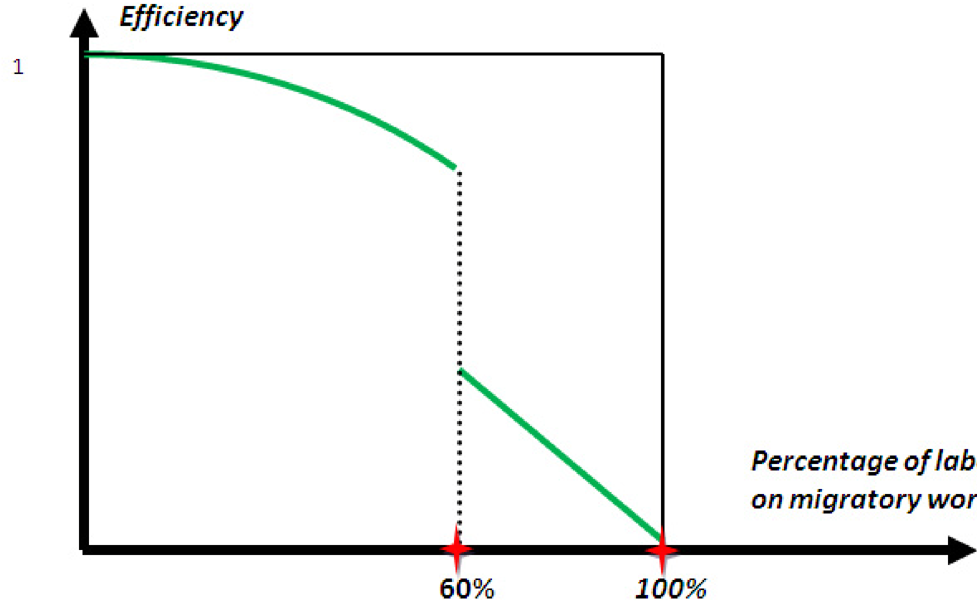


Figure 5-2 Migratory work efficiency function. For each additional unit of labor a household spends on migratory work, its marginal economic return decreases.

Yield functions

Rice yield per unit area is determined by four major factors: fertility of farmland, quality of the irrigation system, management efforts, and machinery usage and other technology. In general, because the households' farmland holdings are currently quite small, they have little incentive to put significant management efforts into crop cultivation or investments into a good quality irrigation system, machinery, and other technology. This situation is compounded by higher economic return on labor from migratory work.

The forms of the rice-yield functions (Figure 5-3) reflect the effects of changes in these factors as the area of farmland managed by a household increases. Δ1 reflects the increase in yield associated with increased efforts when the area of farmland managed by a household reaches 10mu, based on the observation that in V3, because the managed area on average is over 10mu, farmer households show greater efforts in 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 reaches 30mu. When a household manages 30 mu of farmland, if used to grow two-season rice, the household can make a yearly income similar to the higher end income from migratory work. Therefore, it is worth investing in irrigation system improvement. A much larger value of Δ2 for two-season rice than one-season rice reflects the fact that irrigation system functioning affects the yield of two-season rice more because farmers can manage to irrigate rice fields for one season but have difficulty doing so for two seasons. The positive slopes of both lines reflect a constant increase in yield as a result of steadily increasing efforts a household puts in crop cultivation when its farmland area increases.

The differences in rice yields in the three villages reflect different combinations of farmland fertility, irrigation system condition, and management efforts. Therefore, these data serve as the basis for calibrating the parameters of the yield functions. The potential yields at larger scales of farming operations were first estimated for each village (Table 5-4). The potential yields in the three villages at the scale of 30mu were estimated such that they only reflect the differences in farmland fertility. Based on these yields, I estimated the values of α1, α2, Δ1 and Δ2 as shown in Figure 5-3.

Table 5-4 Current 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

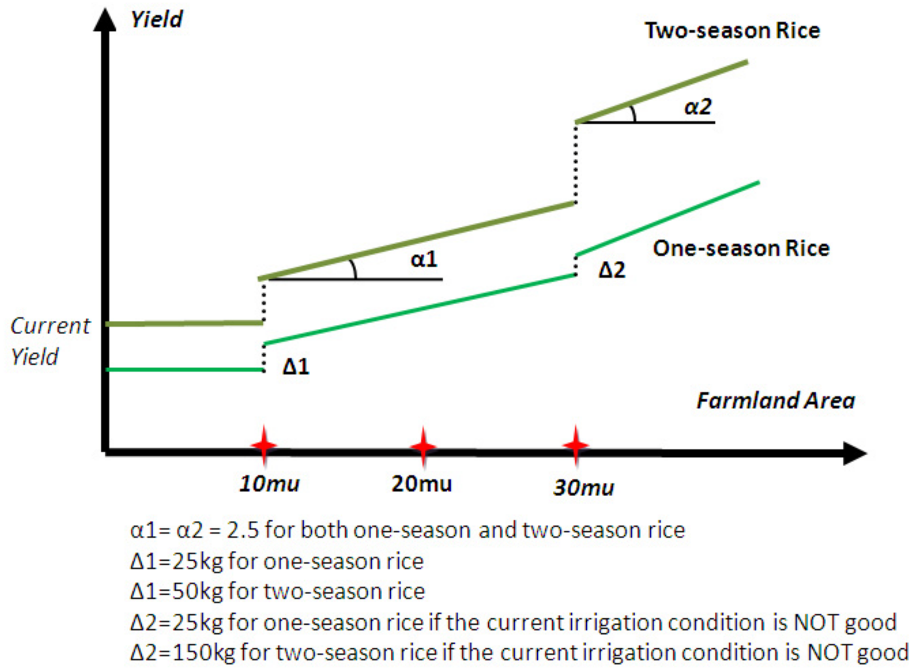


Figure 5-3 Rice yields as a function of the area of farmland managed by a household.

The estimates for rice yields at larger scales of farming operations using these functions, though not observed in the field, are achievable for several reasons. First, the functions' parameters mainly reflect improvements in yields associated with increased management efforts and improvements in irrigation conditions when the scale of farming operations reaches 30mu. They do not reflect any changes in farming or seed technologies. Across surveyed villages, rice cultivation is typically done using traditional methods, and machines are only used to harvest rice in flat fields. The overall level of technology is low. Thus, there is significant room to improve rice yields. And there are multiple and specific ways to improve rice yields in Jiangxi (Pan 2008; Shen and Xu 2009; Zhou 2011). Second, even the largest estimates of yield per mu in V2 and V3 (550kg/850kg) are conservative. According to an article in *China Science and Technology Daily* (China's most authoritative media in science and technology), on November 03, 2009, citing a survey conducted by agricultural experts from the Ministry of Agriculture of China, the publication reported that a breed of rice called "WufengyouT025" yielded 675.3kg per mu and 1300kg per mu for one-season and two-season rice in a model project in Yugan County, Jiangxi Province. *Jiangxi Daily* (an official newspaper run by Jiangxi Government) announced on July 09, 2011 that the agricultural department in Jiangxi Province is working on projects to increase rice yields by applying new breeds and new technology in management. The goal is to achieve 700kg per mu and 1100kg per mu for one-season rice and two-season rice. The government intends to use these projects as models to lead other households in new cultivation practices.

Model validation and verification

In an attempt to generate convincing insights, I validated the model at the macro-level using three different processes after using survey data at the micro-level to calibrate model parameters and initialize the model when it was applicable as described above (Grimm and Railsback 2005; Brown and Robinson 2006; Brown et al 2008). First, I compared relative values of several outcome variables at the village level from model experiments with empirical data in three places, focusing on land-use composition and labor allocation. Next, I conducted experiments to test the model's ability to reproduce land-use changes that have occurred in these villages in the past. Finally, I performed a set of experiments to understand the behavior of the land-rental market in the model and examined how rental prices for land-use rights change in relation to other factors that can affect it.

To make sure the model was built appropriately and did not include important programming errors (i.e., for verification purposes), I followed some general rules of model development. For example, the model was built starting from a simple structure. First, I let farmer households do only what they were observed doing (one crop) in the survey. After the model was able to generate macro-patterns close to those that were observed, I added the other crop choice and let farmers choose from one-season rice and two-season rice. And only after the model was still able to produce the macro-patterns and land-use changes as observed, I added the policy component. I also used many extreme cases to test the program (An et al. 2005). I regard these as regular model development practices, and so will not report all the details.

I ran the model interactively numerous times to observe the behaviors of the system before I ran the experiments described below in batch mode. These observations also informed me how to design the experiments. For example, through interactive model runs, I 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 wildly, but they remain within a limited range of values. On one hand, this pattern characterizes the undesirable resilience of rural development in the region, which increased my confidence that the model plausibly described overall system behavior. On the other hand, it provided input for my 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.

Multiple macro-patterns

The first validation exercise tested the model's ability to reproduce differences in several outcome variables among surveyed villages. For each of the three villages, I 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, I recorded the values of four variables: average rental price for land-use rights per unit area, percentage of off-farm income (off-farm income / 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).

I computed the mean value of each of these variables over the last five steps from each model run and averaged these means over all the model runs (Table 5-5). It has only been five years since the subsidy policy was implemented, and interactive model runs show that the system has adjusted to its effects during this period. Also, because the system does not reach equilibrium without this adjustment, I report the mean value of each variable in the last step over all the model runs as well (Table 5-5). I compared both measures with the empirical data and combined observations from interactive model runs to further understand the dynamics of the system and model behaviors. I also calculated the variances of the means over model runs (Table 5-6). But because none of the values of SD are noticeably large compared to the means, I do not discuss them further.

Both measures show the same relative orders for all the outcome variables across the three villages as those observed in the surveys, interviews, and field observations (Table 5-5). The measures in the last step are closer to the empirical data than the average measures over the 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 rental prices for land-use rights exhibit an increasing trend in each village in the second 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 I cannot establish the absolute link between a step in the model and a year, the validation results suggested that they are not far apart and are close enough to answer my research questions, which are largely about long-term outcomes.

The most noticeable disagreement between modeled outcome and the empirical data is the percentage of off-farm income in V1. This could be the result of inaccuracies in the social surveys. 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 my five-day stay in V1, it was obvious that the villagers largely rely on migratory work for their livelihoods, and the production of many crops is largely for household consumption. In another surveyed village, which has poor farmland resources similar to V1, the percentage of off-farm income based on the surveys was 89.58%, which is closer to the model results.

Table 5-5 Multiple macro-patterns

Village	Avg. Rental Price (YUAN per mu)			Pct. Off-Farm Income			Pct. Two-Season Rice			Pct. Cultivated Area		
	Model		Interview	Model		Survey	Model		Survey/Field Observation	Model		Survey/Field Observation
	Avg. 2^{nd} Prd.	Last Step		Avg. 2^{nd} Prd.	Last Step		Avg. 2^{nd} Prd.	Last Step		Avg. 2^{nd} Prd.	Last Step	
V1	34.3	45.2	About 50 (bad plots are free)	93.6	93.9	76.6	21.1	9.6	8.5 (very little two-season rice)	92.7	87.4	91.3 (some fallowed plots)
V2	102.3	128.6	Between 100 and 150	76.5	76.8	72.4	11.7	9.5	0 (no two-season rice)	98.7	98.3	100 (no fallowed plots)
V3	255.9	339.5	About 300	41.4	42.7	47.6	94.9	95.2	70 (with one-season rice in low-lying areas)	99.4	99.1	100 (no fallowed plots)

Table 5-6 Variations of the outcome variables between model runs (measured by SD)

Village	Avg. Rental Price		Pct. Off-Farm Income		Pct. Two-Season Rice		Pct. Cultivated Area	
	Avg. 2^{nd} Prd.	Last Step	Avg. 2^{nd} Prd.	Last Step	Avg. 2^{nd} Prd.	Last Step	Avg. 2^{nd} Prd.	Last Step
V1	5.6	6.7	0.5	0.5	5.6	4.0	4.3	6.5
V2	14.4	18.6	1.3	1.3	2.7	2.1	1.2	1.5
V3	36.7	41.7	2.8	3.0	1.0	0.88	0.8	1.15

Land-use changes

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

For each of the three villages, I ran the model 100 times with 20 steps each time for each parameter setting. At each step, I recorded the percentage of area planted with two-season rice. I 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. I also calculated the standard deviations of the means over all the model runs.

The model produced a larger proportion of two-season rice in the past in V1 and V2, even with rice yields set to the same values as observed in the present (Table 5-7; Table 5-8). This is consistent with the major land-use change that happened in these two villages (and in most places in PLR), i.e., the conversion of two-season rice to one-season rice. With likely higher yields in 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.

These model experiments also show that even with wages for migratory work set at the current level, farmer households would still be growing more two-season rice if the yields of two-season rice were higher. But such high yields are not obtainable without a well-functioning irrigation system. Because of degraded irrigation systems and the low yields that result from them, farmer households in most places in PLR opt for one-season rice.

Table 5-7 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.

Table 5-8 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.

Behavior of the land-rental market

The third exercise tested the behavior of the rental market for land-use rights. I conducted a series of experiments to explore how modeled rental prices for land-use rights respond to changes in total farmland area, yield of two-season rice (farmland productivity), and migratory work wage. I set the model parameters by varying each of the three variables, while keeping the values of the other two unchanged. The values used for total farmland area, yield of two-season rice, and migratory work wage were 700mu, 600kg per mu, and 40YUAN, respectively, when kept unchanged. 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, I ran the model 100 times with 20 steps each time. At each step, I recorded the average rental price. I 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 results show that the average rental price for land-use rights from model simulations rises as total farmland area decreases, falls as migratory work wage increases, and rises as land productivity increases (Figure 5-4). 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.

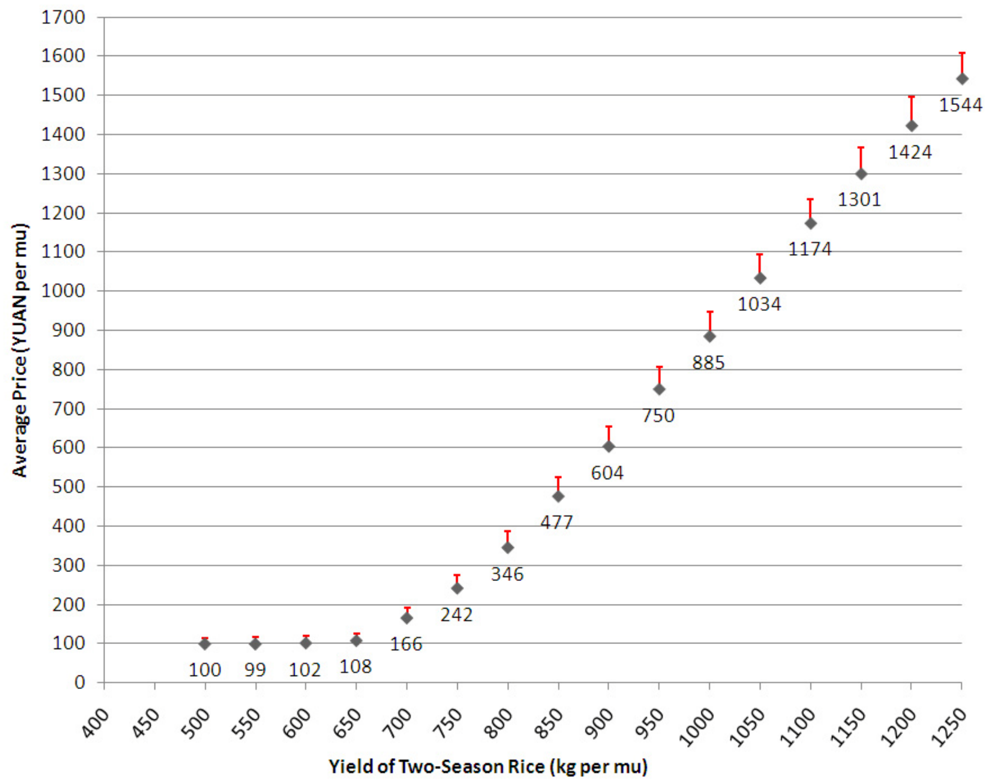


Figure 5-4a Average rental prices for land-use rights vs. farmland productivity. The bars indicate SD.

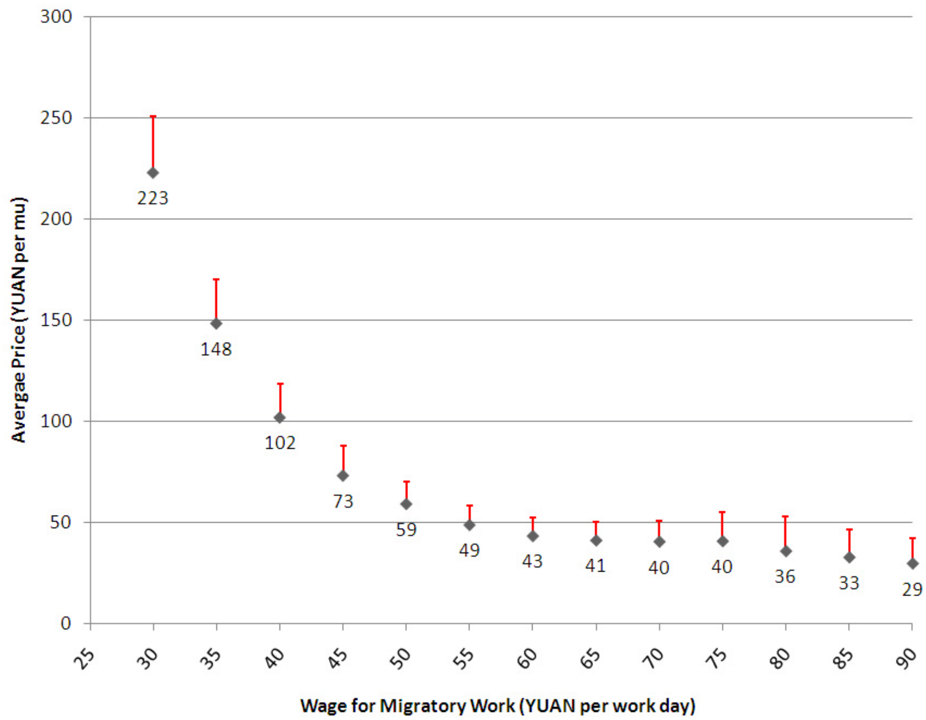


Figure 5-4b Average rental prices for land-use rights vs. wage for migratory work. The bars indicate SD.

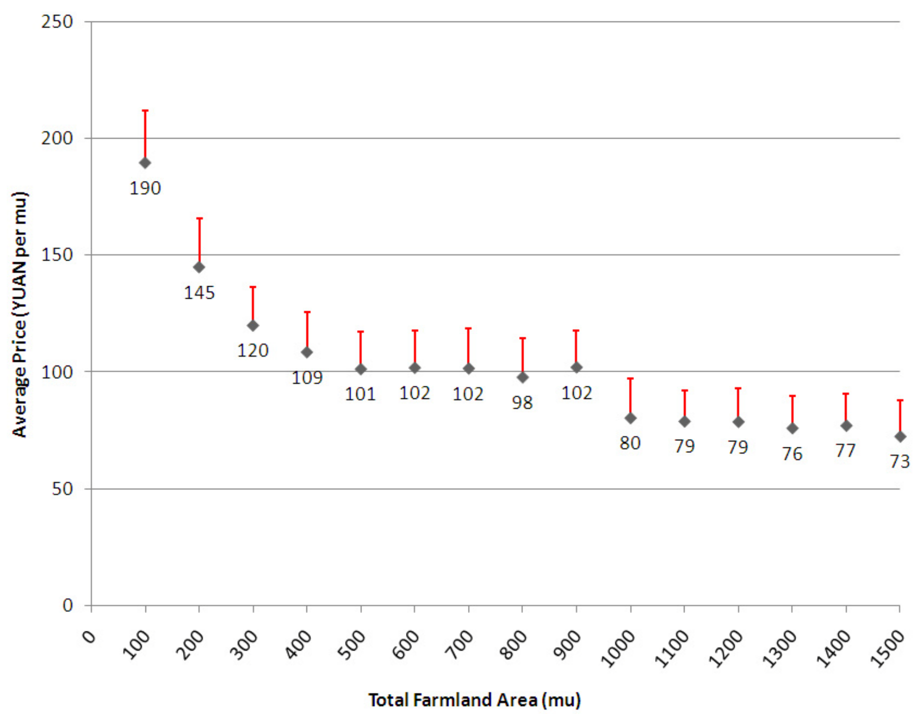


Figure 5-4c Average rental prices for land-use rights vs. farmland area. The bars indicate SD.

Model experiments and results

In this section, I describe the model experiments that are designed to address the research questions and present the results from these experiments. In the next section, I discuss the interpretation of the results and their implications.

Effects of constrained farmland resources

To assess the degree to which limitations in the availability of farmland resources affect the livelihood strategies of farmer households and outcomes, I conducted an experiment that contrasted results for each of the three villages with the parameter *hypo-scenario* set to true, then false. In this experiment, yield functions (with increasing farmland area) were not applied, i.e., assuming constant rice yields as they are now in each village. I compared model outputs from the two scenarios for each village.

I ran the model 100 times for each parameter setting with 20 steps each time. At each step, I recorded the percentage of cultivated area, percentage of off-farm income, average total income, and percentage of labor on migratory work. I computed the means of each of these variables over the last five steps for each model run, and then averaged the means and calculated the variances of the means over all model runs (Table 5-9).

Table 5-9 Effects of constrained farmland resources

Village	**Hypo-Scenario**	**Pct. Cultivated Area**		**Pct. Off-farm Income**		**Avg. Total Income** (1000YUAN)		**Pct. Labor on Migration Work**	
		Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
V1	false	**60.3**	12.0	96.4	0.8	20.5	0.8	93.4	2.0
	true	**156.0**	39.6	90.4	2.5	21.2	0.8	89.4	2.7
V2	false	**96.7**	2.4	81.0	1.3	20.3	1.2	70.9	3.8
	true	**318.0**	30.7	46.9	5.0	25.4	0.9	49.2	5.0
V3	false	**98.3**	1.4	48.3	2.8	24.2	1.3	46.9	4.5
	true	**221.4**	13.9	15.0	3.5	33.5	1.2	18.6	4.3

Efficiency of the private market for transfer of land-use rights

To assess the performance of the land-rental market, I conducted a model experiment that explored the overall trading success rates under realistic levels of household effort put into finding trading partners. For each of the three villages, I ran the model 100 times, with *NumHouseholdTrade* set to 6, then 8, with 20 steps each time. At each step, I recorded the total supply and demand of land-use rights, as well as the trading success rate (total traded area / minimum of total area to rent out and total area to rent in *100). I computed the mean of the trading success rate over the last five steps for each model run, and then calculated the average and standard deviation of the mean over all the model runs (Table 5-10).

Because the results from this model experiment reveal a low trading success rate in V1 (Table 5-10), I conducted more runs to further investigate the performance of the private market in V1. I ran the model in V1 with *SocialEffects* set to false and *NumHouseholdTrade* set to 6, 8, and 10. In a natural Chinese village of about 100 households, typically every household knows every other household, and a household can easily have 10 households with which it maintains good relations. Therefore, these parameter settings still represent realistic levels of effort the farmer household puts in finding trading partners.

Table 5-10 Performance of the private market for transfer of land-use rights

Model Parameter Setting		**Village**	**Avg. Success Rate (%)**	**SD**
NumHouseholdTrade	*SocialEffects*			
6	true	V1	68.5	9.6
		V2	92.7	4.6
		V3	95.9	3.7
8	true	V1	77.4	9.8
		V2	96.2	4.5
		V3	98.1	2.5
6	false	V1	78.8	8.6
8	false	V1	85.3	8.0
10	false	V1	91.0	5.8

Evaluate/explore the effectiveness of policies

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

800YUAN per mu with an increment of 20 YUAN per mu each time). For the purpose of comparison, I report the results for the two policies together.

To explore and evaluate the effectiveness of policies, I examined (i) changes in the state of the system, (ii) economic efficiency, (iii) fairness, and (iv) the trajectory of the system. I used multiple outcome variables to represent the state of the system: (i) total agricultural production, (ii) total income, (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 total income represents the well-being of farmer households, total agricultural production represents the overall development level of the agricultural sector. The two measures are interrelated, but not all the same and can be in conflict. Ideally, government policies should promote agricultural production and the well-being of farmer households at the same time. I used the other variables to further examine various aspects of the agricultural sector: the extent and intensity of farmland utilization and the scales of farming operations. For each variable, at the present stage of rural development higher values indicate better outcomes. I used two variables to measure the economic efficiency of policies: (i) agricultural efficiency (increase of total agricultural production per unit cost), and (ii) income efficiency (increase of total income per unit cost). I discuss fairness of policies in the sense that households with poor farmland resources deserve more compensation. The trajectory of the system reveals the dynamics of the processes and indicates the potential for further growth.

For each of the three villages, I ran the model 100 times for each parameter setting of policy and subsidy amount with 40 steps each time. The 40 steps are divided into two 20-step periods, in the second of which a subsidy policy is in effect. 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, I recorded the values of the state variables and the cost (government subsidy amount) in the second period. A sample report file can be found in Appendix 5-A3.

To measure the state change of the system resulting from a policy, I averaged the each of the five state variables' values over the last five steps in the second 20-step period and compared them with those over the last five steps in the first 20-step period for each model run. I computed the change rates for total agricultural production and total income, as well as the changes in percentage of cultivated area, percentage of farmland in two-season rice, and percentage of farmland managed by the top 10 households. I then averaged the means of changes/change rates of these state variables over all model runs. Using state variables' changes/change rates (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 derive the measures of policies' economic efficiency, I summarized total agricultural production, total income, and total cost in the second 20-step period for each model run. I computed total agricultural production and total income without the policy by multiplying these variables' average values over the last five steps in the first period by 20. The differences in these measures were total increase of agricultural production and total increase of income in a 20-step period as a result of the policy. I then calculated agricultural efficiency by dividing total increase of agricultural production by total cost, and calculated income efficiency by dividing total increase of income by total cost. I averaged the values of agricultural efficiency and income efficiency from all model runs.

I compared the results from model runs with different amounts of subsidy for long-term renters to understand the effects of the new policy in different villages in comparison with the current policy (Figure 5-5). I also examined the variations of the outcome variables between model runs (the coefficient of variation) to understand the uncertainty of the new policy, particularly those variables on which the new policy has an obvious impact (Figure 5-6). Data associated with these figures can be found in Appendix 5-A4 through 5-A7.

I picked a subsidy amount for long-term renters in each village such that the total amount of village subsidy is about equal to what is currently received. I then compared the subsidy's effects with the current policy (Table 5-11). I also compared the total amounts of subsidy to rice production in the three villages to evaluate the fairness of the current policy.

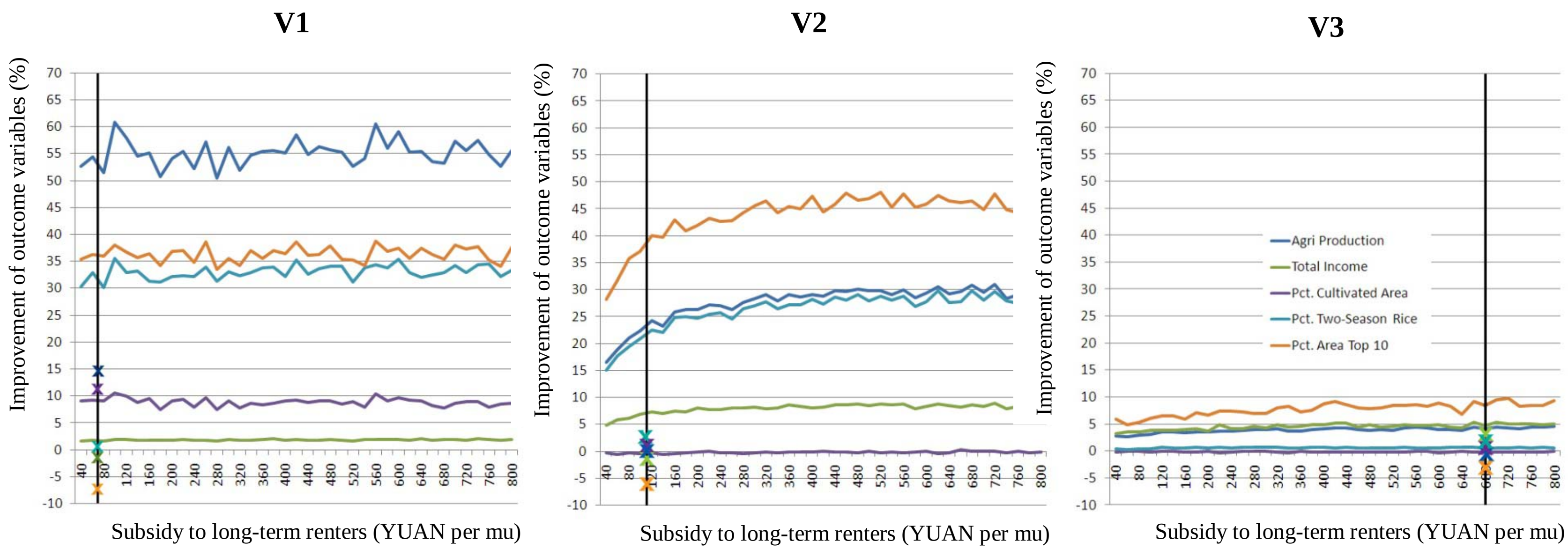


Figure 5-5a Effects of the current policy and the new policy: changes in system state. The vertical lines on the graphs represent the amount of subsidy to renters that makes the total subsidy to a village about equal to what it receives under the current policy. The symbols x indicate the change in the state of the system resulting from the current policy.

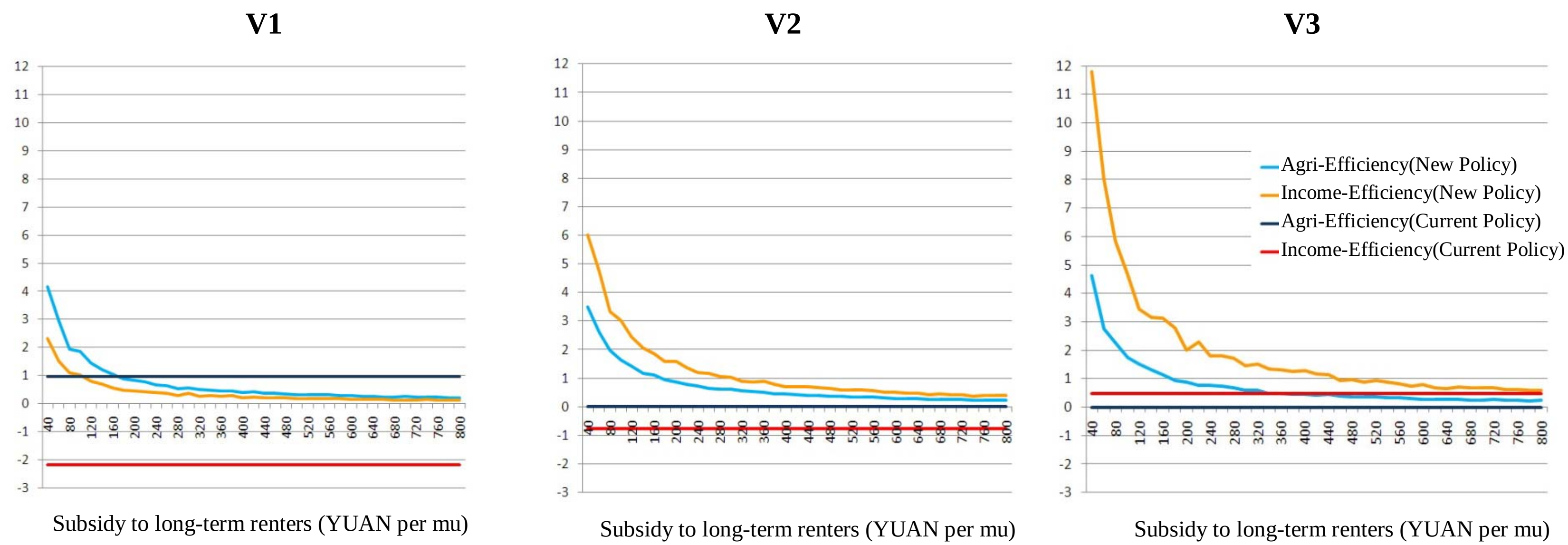


Figure 5-5b Effects of the current policy and the new policy: economic efficiency. The units for the vertical axis are kg per YUAN and YUAN per YUAN for agricultural efficiency and income efficiency respectively.

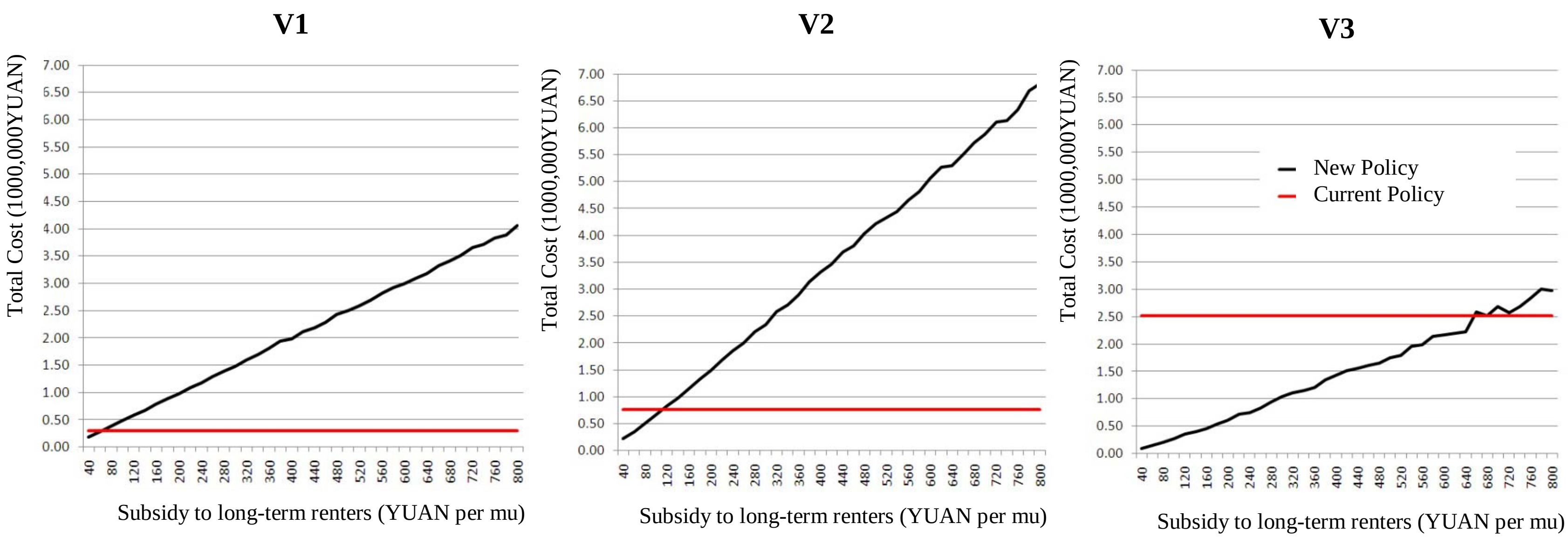


Figure 5-5c Effects of the current policy and the new policy: cost and fairness.

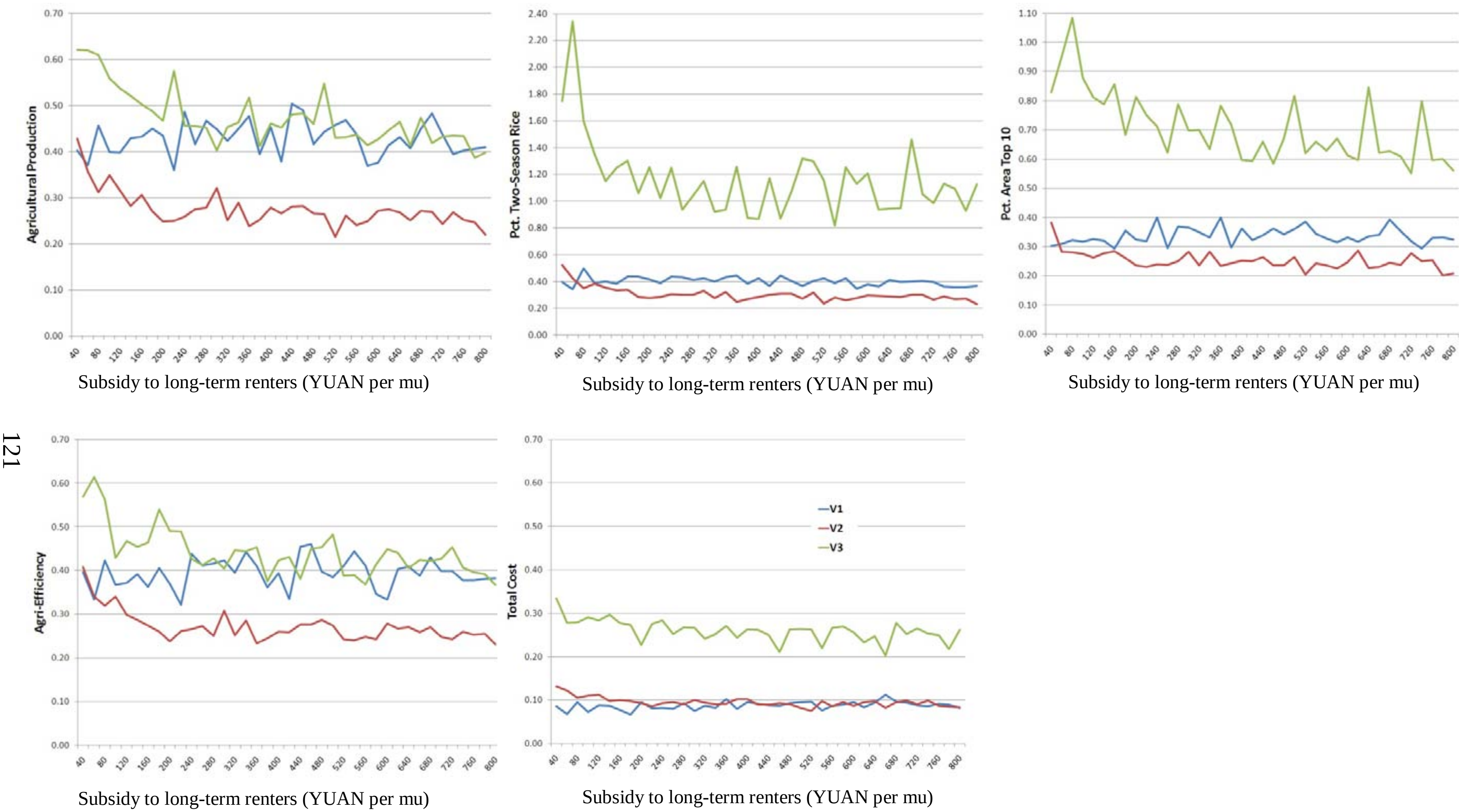


Figure 5-6 Variations of major outcome variables between model runs (measured by coefficient of variation).

Table 5-11 Comparison between the effects of the new policy and the current policy

Aspect	Measures	V1		V2		V3	
		Renter (60YUAN)	Current Policy	Renter (110YUAN)	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	36.28	-7.79	37.94	-6.49	8.49	-2.96
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**

I further examine and discuss the implications of three scenarios of the new policy with different subsidy allocations in three villages (Table 5-12). In each scenario, the total subsidy the government spends in all three villages is about equal to what the government spends now subsidizing rice production. In Scenario A, each village receives about an equal amount of total subsidy. In Scenario B, all the villages receive the same amount of subsidy per unit area (240YUAN per mu). Scenario C represents a more pro-poor policy in which the farmland-poor village (V1) receives more total subsidy than other villages.

Table 5-12 Three scenarios with the new policy

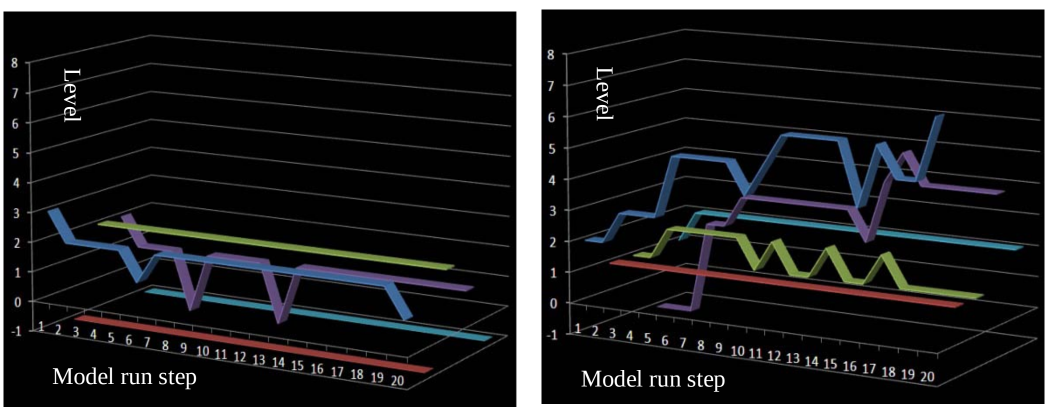
Aspect	Measures	Similar Total Cost (Scenario A)			Same Subsidy per unit area (Scenario B)			Pro-Poor (Scenario C)		
		V1 (240)	**V2** (160)	**V3** (360)	**V1** (240)	**V2** (240)	**V3** (240)	**V1** (360)	**V2** (160)	**V3** (200)
Changes in the State of the System (%)	Agricultural Production	52.15	25.87	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 (YUAN)	in each place	1,177,630	1,140,211	1,203,876	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		

To understand the dynamics of the processes, I separately mapped the system trajectories in a multi-dimensional space under the current policy and the new policy. For the new policy, I picked a scenario (B in Table 5-12) in which each village receives 240YUAN per mu for long-term land-use-right contracts because it has several special properties (further discussed in the next section). Interactive model runs also demonstrated that the state variables exhibited similar patterns of change in the second period, even with different amounts of subsidy provided to long-term renters.

Based on the same model runs for exploring the effects of policies as described above, I computed changes and change rates of the state variables at each step in the second period, relative to the end state in the first period (represented by the mean values of the state variables over the last five steps) for each model run. I classified the changes and change rates at each step into several categories, where each category (called levels) represents a 10% change along each dimension. I used the most frequently encountered level across all model runs to represent the state of the system at a step (Figure 5-7). Data associated with these figures can be found in Appendix 5-A8 through 5-A10.

Current Policy | **New Policy (subsidy = 240YUAN per mu)**

V1



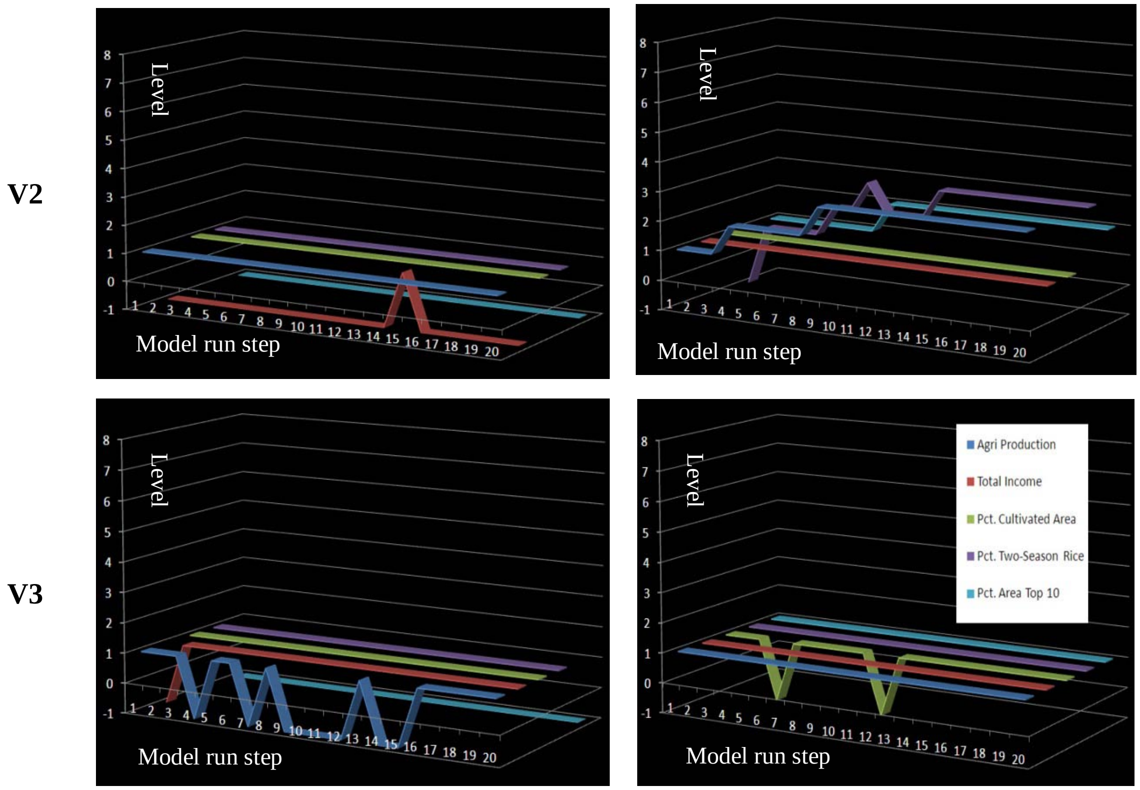


Figure 5-7 Trajectories of the system.

Discussion

Effects of constrained farmland resources

The results from the constrained-farmland experiment suggest that farmer households in PLR are significantly constrained by farmland resources. In the hypothetical scenario, in each village, household agents would cultivate more farmland (about two times more) than they do now, have larger proportions of agricultural income, and spend more labor on crop cultivation (Table 5-9). The degree to which their income would increase depends on the productivity of the farmland (Table 5-9). In V2 and V3, where rice yields are higher, total income would significantly increase. In V1, where the farmland productivity is low, total income would be slightly improved. Therefore, the low profit from crop cultivation may have contributed to, but is not the fundamental reason for, the current limited efforts households put into crop cultivation, which are more a consequence of small farmland holdings. Because these results do not reflect increases in rice yields as farm size increases, I expect farmer households are, in reality, more constrained by the availability of farmland than the model results suggest.

Farmland resources constrain the livelihoods of farmer households and prevent them from achieving optimal level of income in two ways. First, due to farmland shortage, households have to expend labor, which would be more economically efficient in cultivating farmland, on migratory work. Second, limitations in farmland resources create competition for land-use rights, and farmer households have to pay for acquiring land-use rights. The more scarce the farmland resources are in a place and the less productive they are, the less efficiently farmer households use their labor to generate income. Therefore, places with poor farmland resources have an inherent disadvantage with economic development. And households in such places (as in V1) still have to face the same challenges on the off-farm labor market as farmer households in other places. Though farmland resources (or other natural resources) cannot be easily increased or changed, the government can play a positive role in addressing this inequity in natural resource endowments between villages. This role is important in achieving greater equity and a higher development level across rural China.

Efficiency of the current market for transfer of land-use rights

The results from the land-market-efficiency experiment suggest that the current private market sufficiently matches the demand and supply of land-use rights. The simulated trading success rate is over 90% in all three villages when the household agents randomly choose six other household agents for negotiations (even with failures due to bad social relations) in V2 and V3, and if the household agents in V3 randomly choose 10 other household agents without failures due to bad relations (Table 5-10). As explained earlier, these conditions are easily met in a natural Chinese village of about 100 households. Exchanges of land-use rights also often happen between relatives or friends, and the contracts are more stable over time than random selection of trading partners each year as simulated in the model. Therefore, the trading success rate is, in reality, expected to be higher than the model simulations.

The lower trading success rate in V1 relative to V2 and V3 in the model simulations can be explained by the smaller farmland holdings in V1. It takes more effort for a household in V1 to acquire the same amount of area as in V2 and V3. And this may have discouraged farmer households in places with scarce and fragmented farmland from renting in land-use rights for large areas. But even in V1, I met farmers who wanted to contract large areas of farmland for alternative uses. In V2 and V3, higher farmland productivity creates a demand for land-use rights that is consistently higher than the supply over time in model simulations, which contributes to the land-rental market's higher performance in the model than in V1. This is consistent with the field observation that no plots were found fallow in V2 and V3.

It can be inferred that the lack of large-scale farms in rural China is not due to private land-rental market performance but, as the farmer household interviews suggested, to the disincentive associated with short-term land rental contracts. Acquiring land-use rights for large areas will involve arranging contracts beyond relatives and friends. Several interviewed farmers mentioned the risk of contracting large areas. They were particularly worried that contractors could take back the leases simply out of jealousy after they have had improved land use and farmland productivity. Therefore, assuring the security of land-use rights through long-term contracts may help stimulate land rental markets in rural China.

Effectiveness of the current policy

The current policy's modeled effects on rural development are different in different villages. Yet the results from the model experiment suggest that subsidizing rice cultivation does little good for promoting agricultural production and rural income overall and has several undesired effects (Figure 5-5a; Table 5-11). In places with poor farmland resources (as in V1), the current policy increases total agricultural production and the percentage of cultivated area to some degree in the model simulations. This can be explained by the V1's low farmland profitability--the subsidy makes farming a little more profitable on the marginal land. In places 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 the model simulations. In places rich in farmland resources, as in V3, the subsidy does almost nothing to improve the agricultural sector in the model simulations. This outcome can be explained by the high productivity of farmland in V3--households in such places would perform the same regardless of the subsidy, i.e., growing two-season rice and making full use of their farmland. The current policy slightly increases total income in V3 in the model simulations due to large government subsidies. In V1 and V2, subsidies slightly reduce total income in the model simulations, probably because the subsidy increases farming income, attracts more labor to remain on the farm, and therefore, increases competition for farmland. Across all the villages in the model simulations, the subsidy decreases the scale of farming operations, and therefore, the potential of farmland may not be fully realized. Based on the model simulations, the current policy has small or negative economic efficiency in both measures (Figure 5-5b; Table 5-11). It is not fair--places rich in farmland resources receive a large amount of subsidy in addition to their inherent advantages in natural endowments, while farmers with pool farmland resources receive much less subsidy and are left to seek migratory work (Figure 5-5c; Table 5-11).

The simulated system trajectories using the current policy suggest immediate effects that level off quickly (Figure 5-7). The simulated system settles into quasi-equilibrium quickly and indicates no potential for further growth. The undesirable resilience (i.e., agricultural production and rural income are low and difficult to increase) is exactly the main problem with Chinese rural development that government policies aim to solve. The results from this model experiment suggest that subsidizing rice production cannot solve this problem.

Effectiveness of the new policy

The results from the land-rental-subsidy experiment suggest that different villages respond to varying amounts of subsidy for long-term contracts differently. In villages with average farmland resources (V2), increasing subsidy size produces noticeably larger non-linear improvements in the model simulations (Figure 5-5a). Increasing subsidy size, however, does very little to further improve the system in villages with poor or rich farmland resources in the model simulations (V1 and V3) (Figure 5-5a). These results from the model experiment conform to intuitions developed from field observations. 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 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 the intermediate level, and more households would be better off renting out their land-use rights for longer terms as subsidy size increases. Therefore, the total farmland area transferred would increase as the subsidy size increased. The fact that villages with average farmland resources are sensitive to subsidy size in the model is a good sign; the government could use subsidy size as an instrument to effectively improve the system in a majority of villages.

The results from this model experiment suggest that in all places, as subsidy size increases, total cost increases as well, resulting in an economic efficiency decrease. The new policy's modeled economic efficiency appears to have a similar non-linear pattern in relation to subsidy size across locale (Figure 5-5b). Both measures of economic efficiency drop quickly as subsidy size increases and become flat later in the model simulations. Modeled total cost shows a linear relation with increasing subsidy size, but the relationship has different slopes for different villages (Figure 5-5c). Because total cost associated with a subsidy size is essentially determined by the total area transferred through long-term contracts during the 20-step period, the slopes of these lines can be interpreted as the policy's efficiency 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 new policy in stimulating the land-rental market remains positively constant in all places. This suggests 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 places with average farmland resources (V2), indicating that the new policy will be more efficient in stimulating the land rental market in the majority of places. The new policy is found least efficient in stimulating the land rental market in places with rich farmland resources in the model simulations (V3). The relationships generated by the model simulations could be used to identify specific subsidy amounts appropriate for different locations given economic goals and budgetary constraints.

The results from this model experiment suggest that the new subsidy policy for long-term renters has apparent advantages when compared to the current policy, regardless of subsidy size. In the model simulations, the new policy leads to a significantly larger, considerably larger, and slightly larger improvement in total agricultural production in villages with poor farmland resources (as in V1), average farmland resources (as in V2), and rich farmland resources (as in V3) respectively(Figure 5-5b). The largest improvement of V1 agricultural production in model simulations can be explained as resulting from the combined effects of improvements in farmland cultivation rate, proportion of area planted with two-season rice, and scales of farming operations (Figure 5-5a). The agricultural production improvements in the V2 model simulation results from improvements in the proportion of two-season rice and scales of farming operations (Figure 5-5a). With about 100% of its farmland already cultivated in V2, there is no room to improve the extent of farmland utilization. The smallest agricultural production improvement in the V3 model simulation results from small improvements in farming scales, since V3 farmland is already fully utilized in both extent and intensity (Figure 5-5a). Across villages in the model simulations, the policy increases the scale of farming, though to different degrees (Figure 5-5a). It slightly increases total income across villages in the model simulations (more noticeably in villages with average farmland resources) (Figure 5-5a). In villages with average to rich farmland resources (as in V2 and V3), the new policy is more efficient in promoting both agricultural production and income across the range of subsidy according to the model simulations (Figure 5-5b). In places with poor farmland resources (as in V1), the new policy is more efficient in promoting rural income across the range of subsidy size in the model simulations (Figure 5-5b). And the new policy has an additional effect in stimulating land-rental markets across villages (Figure 5-5c).

The results from this model experiment suggest that if the government uses the same amount of money to subsidize long-term renters as it is spending on rice production subsidies in each village, it can achieve better effects in most measures across the board

(Table 5-11; Figure 5-5a; Figure 5-5b; Figure 5-5c). Based on the model simulations, the only disadvantage of the new policy is in changing farmland cultivation rates. The 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 the model simulations. But the increase in farmland cultivation rates under the current policy only translates into a similar degree of increase in agricultural production, and even a small decrease in total income in V1 and V2 in the model simulations. In fact, the results from this model experiment suggest that increasing farmland cultivation rates in villages with marginal land productivity (about 10%, as in V1) is the largest positive effect of the current policy.

The new policy is fairer in nature than the current policy. First, in places with poor farmland resources, rental prices for land-use rights are relatively low, and farmer households that intend to specialize in agriculture can rent large areas at relatively low cost. This compensates for the inherent disadvantage of having poor natural resources. Second, most farmer households in places 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, which will make it easier for those households that intend to specialize in agriculture to acquire large farmland areas. The subsidies the renters receive will improve their urban livelihoods. Thus, every rural household in such places, which tend to be economically less developed than other rural areas, will improve their situation.

The government can also deliberately address the inherent inequality in natural resources by choosing subsidy size. There is significant room for the government to use subsidy size as an instrument to promote rural development and address the issue of fairness simultaneously. The model simulation responses to varying subsidy sizes in different villages suggest that the new policy can play different and effective roles in different villages. The most effective roles of the new policy are (i) to compensate for poor natural endowments, and improve the agricultural sector in places with poor farmland resources; (ii) to use subsidy size as an instrument to stimulate the land-rental market and efficiently increase agricultural production and rural income through larger scales of farming operations in places with average farmland resources; and (iii) to create a social effect by showing that the government cares about farmer households in places with rich farmland resources who sign long term contracts for their land-use rights.

For example, if the government is to provide total subsidies to long-term renters in all three villages about equal to what the government currently spends in subsidizing rice production, the government can allocate the budget differently to reflect these diverse policy roles (Table 5-12). To be fair, the government can give at least the same amount of total subsidy to each village (Scenario A in Table 5-12). 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 5-12). The government can also apply the same amount of subsidy per unit area in all places (Scenario B in Table 5-12). Scenario B has several other properties. In V2, the increasing effects of the new policy begin to level off beginning at 240YUAN in the model simulations (Figure 5-5a). Because the majority of villages have about average farmland resources, I expect this subsidy amount will produce larger overall economic effects. 240YUAN per mu appears to be a reasonable amount--it makes available a total of 4,800YUAN per mu for a 20-year contract, which (plus the rental fee) is likely to inspire farmer households to give up their long-term land-use rights considering that the average wage for migratory work is 9,600YUAN per year. And, in the model simulations, all three villages achieve a similar efficiency in increasing agricultural production with 240YUAN per mu.

The results from this model experiment show that under the new policy, the simulated system goes up more levels along most dimensions than the current policy, indicating a potential to grow further, particularly in agricultural production, intensity of farmland utilization, and farming scales in most places (i.e., places with poor to average farmland resources; Figure 5-7). I expect that in reality, the system has a larger growth potential because the rice-yield functions do not reflect the effects of technology changes and innovations that will happen in large scale farming operations. But places rich in farmland resources do not show a potential for further growth under the new policy in the model simulations, similar to the current policy.

The variations of major outcome variables between model runs are reasonably small for most locales, and several variation characteristics are positive regarding the outcome certainty outcomes of the new policy (Figure 5-6). Noticeably large coefficients of variation are found in villages with rich farmland resources (V3), but because the new policy has very few effects in such places (i.e., the means of the outcome variables are quite small), the outcome variables' range of values over all model runs are not large. The variations of 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 places, the new policy is expected not only to be more efficient in stimulating the land rental market, 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), which is similar to the means of the outcome variables. Therefore, in such locations, the new policy is expected to produce large improvements in the agricultural sector, but the improvements are not expected to change much as subsidy size increases, and neither are the uncertainty of the outcomes.

Based on the above discussions, it is reasonable to conclude that a policy of subsidizing long-term renters is likely to lead the system to a more desirable state in most villages, with considerable improvements in the agricultural sector. However, the policy is unlikely to be effective in improving the agricultural sector in places with rich farmland resources. An alternative policy that encourages collective management of farmland through joint stock partnership or cooperatives might be a better choice for such villages. Areas rich in farmland are important grain production bases in China. Further increasing farming scales in these areas is important for building a truly modern agricultural sector in China and for securing its food sources in the future. By implementing policies based on the needs of different locales in rural China, the government can help farmer households create robust livelihoods. Only through such policy flexibility can a significant change be enacted in a large rural population to improve their situation.

The new policy's effect in increasing overall rural household income will be small across villages (Figure 5-5a). The largest modeled increase in income is below 10% and is present in places with average farmland resources. At the current migratory work wage levels, subsidizing long-term renters is likely to increase total agricultural production and improve many other aspects of the agricultural sector. But that alone is unlikely to induce rural development in China to alter the current state of undesirable resilience.

The new policy can be implemented alongside the existing policy of subsidizing rice production, or alternately, the current policy can first be removed. The new policy is expected to produce the same effects as the previous model simulations have suggested, if the current policy is removed first. The modeled effects of the existing policy are immediate and level off quickly. They should dissolve quickly with no complication when it is removed. However, if the current and new policies co-exist, the effects of the new policy may be dampened -- it may need larger subsidies to achieve the same effects on improving the system than that shown in the model simulations (i.e., when the new policy exists without the existing policy). The subsidy for rice cultivation functions the same way and achieves the same results as increasing the yields of one-season and two-season rice by 25kg and 50kg per mu in each village, which is why that policy's effects are straight forward and create no potential for further growth. But these yield increases are too small to bring significant changes in farmer households' decisions regarding labor allocation between migratory and agricultural work or land allocation between one-season rice and two-season rice. For this reason, the policy produces insignificant effects across villages. The most noticeable effect is increasing farmland cultivation rates in farmland-poor places. Therefore, implementing the new policy on top of the existing policy should function similarly to the new policy being implemented in a slightly different system (i.e., setting the yields of one-season and two-season rice 25kg and 50kg higher than the current values) for each village. Thus, the following insights about the new policy should still hold.

(i) The new policy is likely to considerably improve the agricultural sector and create a potential for it to grow further in most places. But the policy's effect in increasing rural income will be limited across villages. And it is unlikely to improve the agricultural sector in places rich in farmland resources.

(ii) The new policy may improve the agricultural sector more in villages with poor farmland resources than in other villages and can make every household in such villages better off. The government could provide a larger subsidy to further compensate such villages for poor natural resources.

(iii) In villages with average farmland resources, the new policy is expected to (a) produce a non-linear effect in improving the system as subsidy size increases, (b) increase rural income to a larger degree, and (c) be more efficient in stimulating the land rental market. And these outcomes are expected to be less uncertain than in other places. The government, by selecting the subsidy size in the majority of villages may effectively control the overall amount of land-use-right exchanges and the degree to which farmland is concentrated in rural China to keep the development of the agricultural sector synchronized with the growth of the industrial sector.

Limitations of the model

Several factors can affect the quality of the inferences based on the model results. First, the effects of the new policy might be underestimated because the rice yield estimates are conservative given increasing farm size. Furthermore, 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. Second, 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. Third, the model does not reflect environmental variations in farmland plots and only includes the major crop choices. For the questions I intended to address using this model, these details should not affect the directions of the inferences.

The assumptions I made about the system also present some model limitations. The assumption that farmers can always find migratory work at different levels of wage 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. The 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. The rice-yield functions used in the model may lead to an underestimate of the new policy's effects as discussed above. The assumption that farmer households do not hire labor is a real model limitation. 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 allows farmer households to hire in labor, even larger scales of farming operations will be possible, which will result in a greater efficiency in farmland utilization and a greater increase in total agricultural production. However, this growth will also lead to a higher degree of farmland concentration, and therefore, possibly a greater inequity between farmer households. To promote the well-being of a large rural population, the next stage of rural development in China should involve larger-scales of family-oriented farming operations, not large farming cooperatives. The government can place some regulations to guide healthy labor hiring practices and prevent extreme farmland concentration.

In general, the results from the model experiments about farmland constraint, market efficiency, and policy effects are pronounced. With the model calibrated using empirical data and validated by various processes, I believe the insights generated from the model can be useful in the field. Experimenting with the new policy in some villages will be helpful for validating the effects of the new policy and identifying potential problems in practice that the model cannot foresee.

Conclusions

In summary, the insights generated from the agent-based model about the four research questions are as follows. First, limited farmland resources have significantly constrained the livelihoods of farmer households. Low profits from crop cultivation may have contributed to, but are not the fundamental reason for, the low efforts farmer households put into crop cultivation. These limited efforts are more a result of small farmland holdings. Second, the current private market for transfer of land-use rights is sufficient for matching demand and supply. Thus, no other forms of official markets, which would involve more difficulties and efforts in implementation across rural China, are needed. The lack of large-scale farming operations in rural areas is due largely to the insecurity of land-use rights inherent in short-term contracts. Third, the current policy of subsidizing rice cultivation may have done little good and some harm for rural development; it is not a fair policy and can only produce immediate and short-term effects. Fourth, subsidizing long-term renters appears to have apparent advantages in promoting rural development: in most places, this policy is expected to move the system to a more desired state with less cost. It can make every household in farmland-poor villages better off and can be implemented to further address the natural resource inequity between villages. It is also expected to create the potential for continuous future growth. The new policy, however, is unlikely to improve the agricultural system in places with rich farmland resources where a different policy is needed.

Choosing the subsidy size for long-term renters involves a tradeoff between benefits and costs under the constraints of total budget. It depends on the government's priorities and goals. It needs to address inequity as well. The model experiments have generated some insights and useful information about combining and balancing policies' different roles, but how to use the information in decision-making is ultimately in the hands of policy-makers.

The effect of the new policy in increasing rural income is expected to be small across villages, and alone, the new policy is unlikely to induce China's rural development to alter the current state of undesirable resilience. Rural development in China is tightly linked to and depends on the industrial sector's growth. As the industrial sector grows, there will be new dynamics, and government policies will need to adapt to suit new situations while taking into consideration social and environmental variations across rural China.

References

An, L., Linderman, M., Qi, J., Shortridge, A. and Liu, J. (2005) Exploring complexity in a human-environment system: an agent-based spatial model for multidisciplinary and multi-scale integration. *Annals of Association of American Geographers* 95(1): 54-79.

Brown, D.G. and Robinson, D.T. (2006) Effects of heterogeneity in preferences on an agent-based model of urban sprawl. *Ecology and Society*, 11(1): 46.

Brown, D.G., Robinson, D.T., An, L., Nassauer, J.I., Zellner, M., Rand, W., Riolo, R., Page, S.E., and Low, B. (2008) Exurbia from the bottom up: Confronting empirical challenges to characterizing complex systems. *GeoForum*, 39(2): 805-818.

Chi, F. (ed.) (2000) China's Rural Land System Reform into 21st Century. China Economics Press (in Chinese).

Dong, S. (2008) The Optimization Path of Reformation in Rural Land of China. Social Sciences Academic Press (In Chinese).

Grimm, V and Railsback, S. F. (2005) *Individual-based Modeling and Ecology*. Princeton University Press.

He, L. and Huang, J. (2001) On the stability of land-use right and input of fertilizer: An empirical study in Guangdong Province. *China Rural Survey* 5:42-48 (In Chinese).

Jin, S. and Deininger, K. (2009) Land rental markets in the process of rural structural transformation: Productivity and equity impacts from China. *Journal of Comparative Economics* 37(4): 629-646.

Li, Y. and Li, S. (1989) Deep barriers to rural reform on land rights. *Chinese Rural Economy* 6:43-49 (in Chinese).

Luo, Y., Zhang, H. and Gao, K. (1988) Assessment of the current status of household responsibility system and thoughts on future changes. *Economic Research Journal* 11:13-17 (in Chinese).

Parker, D., Manson, S., Janssen, M., Hoffmann, M. and Deadman, P. (2003). Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers 93*(2): 314-337.

Pan, X. (2008) The reasons for low yields of two-season rice in Jiangxi Province and counter measures. *China Rice* 4:1-2 (in Chinese).

Qu, F. (1991) *Theoretical Discussion on Institutions Governing China's Rural Land*. Jiangsu People's Press (in Chinese).

Rozelle, S. and Swinnen, J. F. M. (2004) Success and failure of reform: Insights from the transition of agriculture. *Journal of Economic Literature* 42: 404-56.

Shen, D. and Xu, Y. (2009) Issues on rice production in Jiangxi province and suggestions on future development. *Anhui Agricultural Science Bulletin* 5:104-105 (in Chinese).

Sonntag, B. H, Huang, J., Rozelle, S. and Skerritt, J. H. (eds.) (2005) China's agricultural and rural development in the early 21st century. *ACIAR* (Australian Centre for International Agricultural Research) Monograph No. 116. Available at: http://aciar.gov.au/files/node/642/MN116%20Part%201.pdf.

Tu, Q., Heerink, N. and Xing, L. (2006) Factors affecting the development of land rental markets in China - A case study for Puding County, Guizhou Province. Presented at the Annual Meeting of International Association of Agricultural Economists, August 12-18, 2006, Queensland, Australia. Available at: http://ideas.repec.org/p/ags/iaae06/25547.html

Varian, H. R. (2002) Intermediate Microeconomics: A Modern Approach (Sixth Edition). W. W. Norton & Company, New York.

Wang, X. and Ma, S. (1990) From “Jun Tian” system to “Liang Tian” system: the growth point of the rural land system. *Rural Economic Issues* 2:33-37 (in Chinese).

Wei, Z. (1989) Discussion on agricultural land privatization under state management. *Chinese Rural Economics* 5: 15-22, 34 (in Chinese).

Xinhua, the State News Agency (2008) Announcement: The decisions of the Central Government of China on some important issues regarding promoting rural development reforms. *Xinhua News* 19 October.

Yang, X. and Shi, J. (2001) Theoretical discussion and policy design of reforming rural land system in China. *Rural Economic Issues* 12:46-50 (in Chinese).

Yang X. (2001) Thoughts on several issues about the 30-year-unchangable land policy. *Journal of Shandong Agricultural University (Social Science)* 2:10-15 (in Chinese).

Yao, Y. (2000) The development of the land lease market in rural China. *Land Economics* 76(2): 252-266.

Zhou, L. (2011) Issues on mechanization of rice production and their solutions. *Journal of Chinese Agricultural Information* 1:37-38 (in Chinese).

Appendix to Chapter V

5-A1 Distribution of labor across surveyed villages (in person)

5-A2 Statistics of labor across surveyed villages (in person)

Min	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**	**SD**
0	2.0	4	3.6	5.0	7.0	1.4

5-A3 A sample report file from a model run (V2 with the subsidy to renters set to 240YUAN). Farming income is also recorded at each step but not used in the analyses because it is strongly correlated with agricultural production.

Step	**Agricultural production (kg)**	**Total Income (YUAN)**	**Pct. Cultivated Area**	**Pct. Two-Season Rice**	**Pct. Managed Area Top 10**	**Farming income (YUAN)**	**Cost (Subsidy) (YUAN)**
1	369893.5	1777947.6	100	44.3	20.6	364348	0
2	282184.7	2337073.3	80.5	11.7	29.9	352224.6	0
3	245781.2	2239744.9	65.4	11.9	33.9	313222.2	0
4	297020.2	2199294.4	79.2	7	36.6	385107.3	0
5	361138.5	2045942.9	98.7	10.8	34.3	440460.8	0
6	351289.2	2237692.2	98.2	7.3	32.7	442492.1	0
7	338126.3	2272925	93.6	6.2	33	432115.7	0
8	353757.8	2144732.4	99	5.7	33.4	442984	0
9	363881.3	2140272.8	100	13.1	30.3	442434.2	0
10	350266.1	2145563.4	97	14.3	35.7	426863.9	0
11	359850.2	2195686.3	99.1	8.2	37.7	453207.8	0
12	335060.5	2168308.8	95.1	6.9	31.5	416193.4	0
13	356628.4	2077483.3	96.8	8.2	34	445430.6	0
14	347071.3	2132481.6	96.4	12.5	32.2	423763.2	0
15	343721	2115412.7	97.6	11	34.9	414809.3	0
16	343203.4	2062350.4	98.6	6.7	27.5	415945.6	0
17	338949.1	2153846.8	96.6	6.8	30.3	419871.6	0
18	346827.6	2023433.7	96.8	9.3	30.1	419413	0
19	318371.5	2168034.4	90	6.3	32.7	397115.9	0
20	334393.2	2103920.9	97.3	6.2	33.4	405670.7	0
21	374800.2	2237610.1	101.1	7.6	41.9	479797.9	524573
22	369188.8	2107712.3	100.2	6.3	39.2	466798.8	125799.8
23	381893.8	2167522.4	95.7	20.7	38.8	477316.2	39949.4
24	381787.6	2276525.9	93.1	14.5	42.7	503197.6	83990.7
25	386215.9	2313511.1	94.7	15.2	44.4	507921.2	185108
26	407458.6	1920132.4	100.7	23.4	38.2	497305.7	52183.7
27	404664.4	2029319.4	99.4	20.2	37.3	504786.2	3796.3
28	401316.5	2268768.5	97.6	21.8	39.8	512643.5	141441.9
29	407866.4	2253155.4	95.3	24.5	42.5	527263.1	206109.4
30	394597	2254715.7	92.4	23.3	45.2	511004.3	2246.6
31	433984.2	2183334.1	98.3	28.1	47.7	559651.3	32202.4
32	437648.6	2286154.5	96.2	33.5	46.7	566489	128997.6
33	441606.3	2246414.1	98.1	32.3	43.4	567137.6	133825.3
34	444731.7	2284838.3	98.7	31	47.9	577786.4	12081.4
35	454623.8	2385541.7	98.3	32.1	50.7	601270.1	92933.8
36	445771.7	2327996.4	97.7	31	48.4	586747.3	37135.3
37	445502	2280523.6	97.1	34.2	49.1	577378.7	57856.2
38	449981.4	2335804.6	98.4	33.1	48.6	586618.5	31862.7
39	447047.1	2228962.7	99.4	31	45.8	577740.9	9475
40	454979.5	2319886.8	98.8	33.7	49	594581.1	85178
Avg. steps 16-20	336348.9	2102317.3	95.9	7	30.8	411603.4	
Avg. steps 36-40	448656.3	2298634.8	98.3	32.6	48.2	584613.3	
State Change	33.4	9.3	2.4	15.6	7.4	42	
Others	Total increase: 8365666	Total increase : 44708430	Agri-efficiency: 0.8		Income-efficiency: 1.3		Total cost: 1986746

5-A4 Summary of the effects of different polices in V1

Subsidy to Renters (YUAN)	Changes in the State of the System										Efficiency				Cost	
	Agricultural Production (kg)		Total Income (YUAN)		Pct. Cultivated Area		Pct. Two-Season Rice		Pct. Area Top 10		Agri-Efficiency		Income-Efficiency			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
40	52.56	21.15	1.70	1.23	9.16	6.21	30.31	11.96	17.55	5.31	4.17	1.66	2.32	2.00	187779	16153
60	54.41	20.13	1.73	1.24	9.23	5.86	32.89	11.30	18.03	5.59	2.93	0.98	1.50	1.37	282271	19103
80	51.44	23.48	1.59	1.21	9.02	5.91	30.08	14.99	17.79	5.73	1.93	0.82	1.09	0.88	379027	35843
100	60.88	24.33	1.87	1.34	10.49	6.31	35.48	13.70	18.85	5.97	1.86	0.68	1.01	0.83	482935	35282
120	57.83	23.01	1.86	1.26	10.02	6.10	32.89	13.15	18.37	5.98	1.45	0.54	0.79	0.64	580306	51140
140	54.50	23.35	1.83	1.24	8.82	7.08	33.15	12.67	17.81	5.70	1.21	0.47	0.70	0.52	673752	58747
160	55.13	23.83	1.82	1.24	9.59	6.68	31.25	13.71	17.97	5.27	1.03	0.38	0.57	0.48	783433	60501
180	50.70	22.83	1.75	1.39	7.44	6.65	31.11	13.60	17.05	6.06	0.87	0.35	0.48	0.48	883823	59442
200	54.14	23.55	1.71	1.22	9.12	6.80	32.11	13.39	18.14	5.87	0.81	0.30	0.45	0.41	980392	93725
220	55.37	19.92	1.86	1.27	9.39	5.42	32.33	12.51	18.26	5.83	0.77	0.25	0.42	0.35	1086606	87539
240	52.15	25.39	1.85	1.44	7.97	6.09	32.22	14.14	17.27	6.90	0.67	0.30	0.40	0.31	1177630	96429
260	57.13	23.76	1.80	1.26	9.60	6.54	34.00	14.66	19.13	5.66	0.64	0.26	0.36	0.27	1288881	102161
280	50.46	23.55	1.59	1.22	7.53	6.54	31.28	12.88	16.65	6.15	0.54	0.22	0.28	0.27	1388638	129107
300	56.12	25.16	1.97	1.37	9.04	6.88	33.10	14.03	17.61	6.45	0.56	0.24	0.37	0.26	1484105	110516
320	51.83	21.93	1.74	1.34	7.79	6.19	32.37	12.92	17.10	5.97	0.49	0.19	0.27	0.23	1594903	138616
340	54.70	24.63	1.79	1.25	8.63	6.90	32.84	14.16	18.46	6.11	0.48	0.21	0.28	0.24	1702434	140541
360	55.36	26.41	1.92	1.29	8.35	7.30	33.74	14.99	17.50	6.99	0.46	0.19	0.26	0.19	1804933	183405
380	55.62	21.92	2.13	1.29	8.58	5.63	33.87	13.03	18.48	5.50	0.44	0.16	0.28	0.20	1937301	154544
400	55.08	24.99	1.76	1.23	9.15	7.35	32.14	13.65	18.17	6.57	0.40	0.16	0.21	0.20	1986796	188975
420	58.44	22.15	1.97	1.49	9.27	5.81	35.19	12.94	19.14	6.18	0.42	0.14	0.23	0.20	2112093	193017
440	54.88	27.62	1.76	1.23	8.82	7.48	32.59	14.48	17.99	6.09	0.37	0.17	0.21	0.16	2183383	193334
460	56.26	27.53	1.84	1.26	9.01	7.33	33.64	13.62	17.85	6.45	0.37	0.17	0.21	0.16	2286803	199581
480	55.70	23.22	1.88	1.29	9.04	6.30	34.02	12.55	18.78	6.42	0.34	0.13	0.19	0.15	2434381	226407
500	55.27	24.48	1.84	1.41	8.57	6.39	34.09	13.72	17.72	6.37	0.32	0.12	0.17	0.16	2507978	237451
520	52.58	24.08	1.70	1.35	8.91	7.17	31.17	13.19	17.54	6.77	0.31	0.13	0.17	0.15	2592942	250884
540	54.07	25.28	1.93	1.28	7.86	7.44	33.84	13.15	16.99	5.84	0.30	0.13	0.17	0.14	2697386	204271
560	60.53	26.52	1.88	1.26	10.33	6.43	34.44	14.64	19.17	6.28	0.31	0.13	0.16	0.13	2818724	246014
580	55.92	20.65	1.92	1.37	9.05	6.32	33.78	11.74	18.16	5.73	0.28	0.10	0.17	0.14	2928001	261059
600	59.08	22.23	1.91	1.10	9.73	6.00	35.32	13.40	18.53	6.12	0.29	0.10	0.15	0.12	2989668	285268
620	55.26	22.86	1.81	1.27	9.26	6.81	32.97	12.03	17.65	5.60	0.27	0.11	0.14	0.12	3094430	258985
640	55.44	23.90	2.02	1.23	9.11	7.31	31.97	13.23	18.60	6.22	0.25	0.10	0.16	0.12	3182552	297355
660	53.51	21.81	1.74	1.25	8.19	6.61	32.42	12.82	17.85	6.09	0.23	0.09	0.14	0.10	3328002	376382
680	53.26	23.94	1.92	1.40	7.79	6.50	32.97	13.22	17.55	6.88	0.23	0.10	0.13	0.12	3416922	327740
700	57.30	27.70	1.94	1.28	8.71	7.57	34.24	13.85	18.81	6.65	0.24	0.10	0.13	0.11	3512300	330035
720	55.49	24.25	1.77	1.35	8.91	6.25	32.97	13.05	18.43	5.88	0.23	0.09	0.13	0.11	3650315	321226
740	57.44	22.68	2.14	1.28	8.96	6.43	34.43	12.44	18.76	5.49	0.23	0.09	0.15	0.11	3720168	319510
760	54.80	22.06	1.94	1.38	7.88	6.11	34.47	12.36	17.59	5.79	0.22	0.08	0.13	0.11	3831304	348700
780	52.70	21.39	1.74	1.32	8.45	6.65	32.18	11.57	16.97	5.63	0.20	0.07	0.11	0.10	3882634	344457
800	55.53	22.76	1.98	1.23	8.59	5.99	33.35	12.26	18.76	6.08	0.20	0.08	0.12	0.09	4059893	335698
Current Policy	14.77	7.95	-1.37	1.07	13.30	4.68	0.91	2.36	-3.99	3.43	0.96	0.41	-2.19	1.17	291905	8504

5-A5 Summary of the effects of different polices in V2

Subsidy to Renters (YUAN)	**Changes in the State of the System**										**Efficiency**				**Cost**	
	Agricultural Production (kg)		Total Income (YUAN)		Pct. Cultivated Area		Pct. Two-Season Rice		Pct. Area Top 10		Agri-Efficiency		Income-Efficiency			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
40	16.58	7.09	4.79	2.69	-0.28	1.20	15.05	7.89	9.35	3.57	3.48	1.42	6.00	3.94	221572	29103
60	18.81	6.70	5.85	2.37	-0.53	1.32	17.62	7.48	10.54	2.99	2.61	0.89	4.75	2.11	350582	42788
80	21.07	6.57	6.19	2.80	-0.28	1.37	19.40	6.79	11.85	3.32	1.98	0.63	3.32	1.67	499674	53008
100	22.35	7.78	6.84	2.72	-0.44	1.31	20.94	8.07	12.39	3.42	1.63	0.55	3.03	1.22	661191	73356
110	22.98	7.14	7.08	2.72	-0.32	1.37	21.68	7.31	12.58	3.63	1.51	0.48	2.78	1.08	739247	74534
120	24.25	7.64	7.29	2.55	-0.26	1.58	22.51	7.97	13.29	3.50	1.43	0.43	2.43	0.99	829329	93815
140	23.20	6.55	7.07	2.71	-0.53	1.34	22.14	7.39	13.08	3.63	1.17	0.34	2.06	0.88	971160	94796
160	25.87	7.93	7.48	3.26	-0.44	1.41	24.86	8.45	14.15	4.02	1.10	0.30	1.87	0.78	1140212	113816
180	26.30	7.11	7.39	2.40	-0.22	1.33	25.00	7.14	13.60	3.54	0.95	0.25	1.58	0.51	1329733	129186
200	26.29	6.53	8.05	2.92	-0.19	1.43	24.62	6.87	13.94	3.29	0.87	0.21	1.57	0.59	1481775	138084
220	27.16	6.79	7.72	2.31	-0.04	1.27	25.46	7.30	14.32	3.29	0.79	0.21	1.37	0.47	1684046	144758
240	27.07	7.00	7.83	2.58	-0.23	1.40	25.74	7.87	14.24	3.39	0.72	0.19	1.20	0.44	1862593	173711
260	26.25	7.22	8.08	2.57	-0.28	1.44	24.52	7.43	14.18	3.36	0.64	0.17	1.17	0.40	2001089	189762
280	27.63	7.69	8.05	2.65	-0.39	1.28	26.41	8.01	14.67	3.67	0.62	0.15	1.05	0.36	2207440	200214
300	28.28	9.07	8.21	2.88	-0.23	1.40	27.00	8.91	15.11	4.28	0.60	0.19	1.04	0.37	2345420	235348
320	29.12	7.31	7.94	2.69	-0.16	1.37	27.82	7.67	15.39	3.62	0.55	0.14	0.88	0.31	2584516	241770
340	27.97	8.07	8.12	2.90	-0.32	1.47	26.49	8.57	14.74	4.16	0.52	0.15	0.87	0.30	2714621	244663
360	29.08	6.92	8.57	2.52	-0.11	1.35	27.24	6.82	15.06	3.53	0.50	0.12	0.88	0.29	2899359	264758
380	28.59	7.22	8.40	2.39	-0.17	1.49	27.25	7.34	14.97	3.65	0.46	0.11	0.79	0.26	3133252	321099
400	29.12	8.12	8.05	2.61	-0.08	1.23	28.13	8.00	15.62	3.94	0.44	0.11	0.70	0.25	3316741	338847
420	28.74	7.64	8.23	2.57	0.01	1.37	27.39	8.29	14.75	3.68	0.41	0.11	0.69	0.25	3455638	309253
440	29.79	8.37	8.59	2.85	-0.08	1.42	28.59	8.87	15.30	4.06	0.41	0.11	0.70	0.23	3686457	328909
460	29.66	8.35	8.64	2.98	-0.11	1.29	28.08	8.72	15.86	3.74	0.39	0.11	0.66	0.23	3796777	353417
480	30.11	8.02	8.75	2.45	-0.31	1.43	29.02	7.93	15.59	3.67	0.37	0.11	0.63	0.20	4029906	363492
500	29.74	7.89	8.49	2.69	0.01	1.48	27.87	8.87	15.55	4.11	0.35	0.10	0.58	0.21	4213291	347660
520	29.86	6.44	8.75	2.54	-0.23	1.37	28.75	6.76	15.91	3.28	0.35	0.08	0.60	0.20	4327237	322923
540	29.04	7.58	8.62	2.68	-0.17	1.30	27.99	7.86	15.15	3.69	0.33	0.08	0.58	0.17	4439115	433445
560	29.90	7.20	8.81	2.61	-0.24	1.47	28.79	7.52	15.79	3.71	0.33	0.08	0.57	0.18	4649365	396716
580	28.55	7.12	7.96	2.28	-0.11	1.46	26.89	7.44	14.96	3.36	0.30	0.07	0.50	0.16	4818084	455301
600	29.31	7.97	8.39	2.99	-0.01	1.44	27.71	8.21	15.32	3.78	0.29	0.08	0.49	0.19	5053856	438200
620	30.54	8.40	8.71	3.01	-0.36	1.51	29.76	8.74	15.82	4.52	0.29	0.08	0.49	0.17	5265931	503721
640	29.28	7.85	8.49	2.52	-0.21	1.26	27.57	8.00	15.41	3.50	0.28	0.08	0.47	0.16	5299982	518657
660	29.69	7.46	8.22	2.50	0.25	1.47	27.69	7.94	15.29	3.52	0.26	0.07	0.43	0.14	5502419	454104
680	30.79	8.36	8.68	2.74	-0.05	1.52	29.75	9.00	15.47	3.80	0.26	0.07	0.44	0.15	5719295	546075
700	29.47	7.95	8.36	2.64	0.00	1.35	28.00	8.41	14.96	3.55	0.25	0.06	0.41	0.14	5883333	578131
720	31.04	7.54	8.95	2.94	-0.04	1.60	29.66	7.80	15.85	4.40	0.25	0.06	0.43	0.14	6102125	551786
740	28.29	7.60	7.91	3.05	-0.33	1.54	27.84	8.04	14.91	3.74	0.23	0.06	0.38	0.15	6131766	607687
760	29.05	7.32	8.28	2.80	0.06	1.44	27.41	7.36	14.76	3.75	0.23	0.06	0.39	0.14	6331836	547650
780	30.92	7.64	8.74	2.43	-0.22	1.38	29.55	8.05	16.20	3.26	0.23	0.06	0.38	0.12	6683523	561916
800	29.65	6.54	9.01	2.56	-0.16	1.43	28.06	6.52	15.56	3.24	0.22	0.05	0.39	0.12	6817968	567884
Current Policy	0.08	1.58	-1.24	2.06	0.85	1.03	2.27	1.60	-2.22	1.92	0.02	0.11	-0.77	0.84	755955	6325

5-A6 Summary of the effects of different polices in V3

Subsidy to Renters (YUAN)	**Changes in the State of the System**										**Efficiency**				**Cost**	
	Agricultural Production (kg)		Total Income (YUAN)		Pct. Cultivated Area		Pct. Two-Season Rice		Pct. Area Top 10		Agri-Efficiency		Income-Efficiency			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
40	2.76	1.71	3.17	2.37	-0.13	0.81	0.41	0.71	1.59	1.32	4.63	2.63	11.80	9.75	95251	31824
60	2.61	1.62	3.48	2.02	-0.10	0.82	0.32	0.76	1.32	1.25	2.75	1.69	8.00	6.55	146858	40840
80	2.95	1.80	3.51	2.26	0.01	0.91	0.41	0.66	1.40	1.51	2.26	1.27	5.84	4.74	209592	58420
100	3.14	1.75	3.81	2.33	-0.12	0.89	0.47	0.63	1.61	1.42	1.74	0.75	4.65	3.32	280427	81668
120	3.54	1.90	3.89	2.73	-0.08	0.84	0.64	0.73	1.72	1.40	1.51	0.71	3.44	3.05	352845	99938
140	3.49	1.82	3.80	2.35	-0.05	0.88	0.52	0.65	1.71	1.35	1.30	0.59	3.17	2.32	404594	120131
160	3.33	1.67	4.02	2.23	-0.23	0.83	0.50	0.66	1.58	1.36	1.13	0.52	3.13	2.13	449807	124922
180	3.51	1.71	4.16	2.46	-0.14	0.76	0.63	0.67	1.88	1.29	0.94	0.51	2.78	2.33	537617	146934
200	3.47	1.62	3.74	2.37	-0.01	0.79	0.51	0.63	1.77	1.44	0.89	0.44	2.01	1.55	602486	136906
220	3.69	2.12	4.83	2.51	-0.34	0.68	0.63	0.64	1.97	1.48	0.77	0.38	2.30	1.07	721510	198934
240	3.67	1.67	4.12	2.35	-0.15	0.80	0.58	0.72	1.96	1.39	0.76	0.33	1.81	1.37	748427	212652
260	3.84	1.75	4.15	2.63	-0.03	0.75	0.68	0.64	1.95	1.21	0.73	0.30	1.80	1.32	826593	208346
280	3.93	1.78	4.53	2.50	-0.12	0.84	0.64	0.67	1.88	1.48	0.68	0.29	1.71	1.05	935817	250040
300	4.04	1.63	4.28	2.62	-0.05	0.75	0.66	0.76	1.82	1.27	0.60	0.24	1.47	1.05	1039169	276251
320	4.12	1.87	4.80	2.26	-0.19	0.86	0.64	0.59	2.11	1.47	0.60	0.27	1.51	0.78	1102847	265753
340	3.68	1.70	4.43	2.57	-0.29	0.75	0.60	0.56	2.20	1.39	0.49	0.22	1.33	0.81	1146662	289171
360	3.66	1.89	4.50	2.40	-0.08	0.76	0.51	0.64	1.91	1.49	0.48	0.22	1.33	0.69	1203876	325368
380	4.04	1.66	4.87	2.15	-0.18	0.72	0.76	0.66	2.01	1.44	0.46	0.17	1.27	0.64	1347245	328897
400	4.19	1.93	4.90	2.35	-0.15	0.73	0.71	0.62	2.34	1.39	0.45	0.19	1.28	0.60	1428515	374355
420	4.25	1.92	5.14	2.83	-0.19	0.81	0.61	0.71	2.44	1.45	0.41	0.18	1.17	0.64	1517573	397458
440	4.27	2.05	5.13	2.57	-0.20	0.95	0.75	0.65	2.28	1.50	0.44	0.17	1.14	0.62	1550069	386990
460	4.03	1.95	4.47	2.17	-0.16	0.82	0.62	0.67	2.16	1.26	0.40	0.18	0.94	0.49	1614928	340309
480	3.84	1.77	4.79	2.50	-0.14	0.80	0.54	0.71	2.09	1.40	0.37	0.17	0.97	0.61	1651276	432765
500	3.91	2.14	4.44	2.56	-0.14	0.75	0.55	0.71	2.13	1.74	0.35	0.17	0.87	0.60	1752172	462884
520	3.88	1.67	4.62	2.46	-0.14	0.83	0.58	0.67	2.24	1.39	0.35	0.14	0.95	0.53	1796760	471240
540	4.20	1.81	4.93	2.52	-0.19	0.77	0.74	0.61	2.25	1.49	0.34	0.13	0.88	0.48	1964595	432592
560	4.36	1.91	4.76	2.30	-0.03	0.69	0.59	0.74	2.29	1.44	0.34	0.13	0.83	0.47	1992817	530418
580	4.33	1.79	4.66	2.83	-0.09	0.84	0.52	0.59	2.23	1.50	0.32	0.13	0.73	0.47	2134165	576627
600	3.92	1.67	4.81	2.71	-0.30	0.83	0.59	0.72	2.37	1.45	0.28	0.13	0.79	0.45	2164182	553201
620	3.92	1.75	4.37	2.63	-0.19	0.91	0.71	0.67	2.22	1.32	0.28	0.12	0.68	0.46	2190119	511081
640	3.79	1.76	4.27	2.51	-0.10	0.79	0.68	0.64	1.83	1.54	0.27	0.11	0.66	0.39	2218791	549016
660	4.43	1.83	5.24	2.59	-0.20	0.90	0.73	0.69	2.44	1.51	0.27	0.11	0.71	0.38	2580608	522918
680	4.06	1.92	4.72	2.65	-0.15	0.87	0.48	0.70	2.27	1.43	0.24	0.10	0.68	0.35	2517222	698441
700	4.40	1.84	5.34	2.58	-0.15	0.76	0.60	0.63	2.52	1.54	0.25	0.11	0.69	0.33	2688573	678505
720	4.27	1.85	4.99	2.24	-0.22	0.92	0.60	0.59	2.60	1.43	0.26	0.12	0.69	0.37	2573107	680317
740	4.13	1.80	5.00	2.79	-0.19	0.83	0.67	0.76	2.21	1.77	0.24	0.10	0.62	0.39	2678410	679050
760	4.39	1.90	5.07	2.43	-0.18	0.91	0.61	0.67	2.27	1.35	0.25	0.10	0.61	0.35	2840477	707461
780	4.36	1.69	4.89	2.23	-0.20	0.83	0.72	0.67	2.25	1.35	0.23	0.09	0.59	0.31	3009001	653787
800	4.52	1.80	4.99	2.27	-0.02	0.88	0.62	0.69	2.47	1.38	0.24	0.09	0.58	0.28	2976864	778096
Current Policy	-0.09	0.87	3.01	2.30	0.41	0.70	0.57	0.62	-0.81	0.98	-0.01	0.06	0.46	0.33	2513998	5591

5-A7 Coefficients of variation of major outcome variables in three villages

Subsidy to Renters (YUAN)	**Agricultural Production**			**Pct. Two-Season Rice**			**Pct. Area Top 10**			**Agri-Efficiency**			**Total Cost**		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
40	0.40	0.43	0.62	0.39	0.52	1.75	0.30	0.38	0.83	0.40	0.41	0.57	0.09	0.13	0.33
60	0.37	0.36	0.62	0.34	0.42	2.34	0.31	0.28	0.95	0.33	0.34	0.61	0.07	0.12	0.28
80	0.46	0.31	0.61	0.50	0.35	1.60	0.32	0.28	1.08	0.42	0.32	0.56	0.09	0.11	0.28
100	0.40	0.35	0.56	0.39	0.39	1.35	0.32	0.28	0.88	0.37	0.34	0.43	0.07	0.11	0.29
120	0.40	0.32	0.54	0.40	0.35	1.15	0.33	0.26	0.81	0.37	0.30	0.47	0.09	0.11	0.28
140	0.43	0.28	0.52	0.38	0.33	1.25	0.32	0.28	0.79	0.39	0.29	0.45	0.09	0.10	0.30
160	0.43	0.31	0.50	0.44	0.34	1.30	0.29	0.28	0.86	0.36	0.27	0.46	0.08	0.10	0.28
180	0.45	0.27	0.49	0.44	0.29	1.06	0.36	0.26	0.68	0.41	0.26	0.54	0.07	0.10	0.27
200	0.43	0.25	0.47	0.42	0.28	1.25	0.32	0.24	0.81	0.37	0.24	0.49	0.10	0.09	0.23
220	0.36	0.25	0.57	0.39	0.29	1.02	0.32	0.23	0.75	0.32	0.26	0.49	0.08	0.09	0.28
240	0.49	0.26	0.46	0.44	0.31	1.25	0.40	0.24	0.71	0.44	0.27	0.43	0.08	0.09	0.28
260	0.42	0.28	0.46	0.43	0.30	0.94	0.30	0.24	0.62	0.41	0.27	0.41	0.08	0.09	0.25
280	0.47	0.28	0.45	0.41	0.30	1.04	0.37	0.25	0.79	0.42	0.25	0.43	0.09	0.09	0.27
300	0.45	0.32	0.40	0.42	0.33	1.15	0.37	0.28	0.70	0.42	0.31	0.41	0.07	0.10	0.27
320	0.42	0.25	0.45	0.40	0.28	0.92	0.35	0.24	0.70	0.39	0.25	0.45	0.09	0.09	0.24
340	0.45	0.29	0.46	0.43	0.32	0.94	0.33	0.28	0.63	0.44	0.29	0.44	0.08	0.09	0.25
360	0.48	0.24	0.52	0.44	0.25	1.26	0.40	0.23	0.78	0.41	0.23	0.45	0.10	0.09	0.27
380	0.39	0.25	0.41	0.38	0.27	0.87	0.30	0.24	0.72	0.36	0.24	0.38	0.08	0.10	0.24
400	0.45	0.28	0.46	0.42	0.28	0.87	0.36	0.25	0.60	0.39	0.26	0.42	0.10	0.10	0.26
420	0.38	0.27	0.45	0.37	0.30	1.17	0.32	0.25	0.59	0.33	0.26	0.43	0.09	0.09	0.26
440	0.50	0.28	0.48	0.44	0.31	0.87	0.34	0.27	0.66	0.45	0.28	0.38	0.09	0.09	0.25
460	0.49	0.28	0.48	0.40	0.31	1.07	0.36	0.24	0.58	0.46	0.28	0.45	0.09	0.09	0.21
480	0.42	0.27	0.46	0.37	0.27	1.32	0.34	0.24	0.67	0.40	0.29	0.45	0.09	0.09	0.26
500	0.44	0.27	0.55	0.40	0.32	1.30	0.36	0.26	0.82	0.39	0.27	0.48	0.09	0.08	0.26
520	0.46	0.22	0.43	0.42	0.23	1.15	0.39	0.21	0.62	0.41	0.24	0.39	0.10	0.07	0.26
540	0.47	0.26	0.43	0.39	0.28	0.82	0.34	0.24	0.66	0.44	0.24	0.39	0.08	0.10	0.22
560	0.44	0.24	0.44	0.43	0.26	1.25	0.33	0.23	0.63	0.41	0.25	0.37	0.09	0.09	0.27
580	0.37	0.25	0.41	0.35	0.28	1.13	0.32	0.22	0.67	0.35	0.24	0.41	0.09	0.09	0.27
600	0.38	0.27	0.43	0.38	0.30	1.21	0.33	0.25	0.61	0.33	0.28	0.45	0.10	0.09	0.26
620	0.41	0.28	0.45	0.36	0.29	0.94	0.32	0.29	0.60	0.40	0.27	0.44	0.08	0.10	0.23
640	0.43	0.27	0.46	0.41	0.29	0.94	0.33	0.23	0.85	0.41	0.27	0.41	0.09	0.10	0.25
660	0.41	0.25	0.41	0.40	0.29	0.95	0.34	0.23	0.62	0.39	0.26	0.42	0.11	0.08	0.20
680	0.45	0.27	0.47	0.40	0.30	1.46	0.39	0.25	0.63	0.43	0.27	0.42	0.10	0.10	0.28
700	0.48	0.27	0.42	0.40	0.30	1.05	0.35	0.24	0.61	0.40	0.25	0.43	0.09	0.10	0.25
720	0.44	0.24	0.43	0.40	0.26	0.99	0.32	0.28	0.55	0.40	0.24	0.45	0.09	0.09	0.26
740	0.39	0.27	0.44	0.36	0.29	1.13	0.29	0.25	0.80	0.38	0.26	0.41	0.09	0.10	0.25
760	0.40	0.25	0.43	0.36	0.27	1.09	0.33	0.25	0.60	0.38	0.25	0.40	0.09	0.09	0.25
780	0.41	0.25	0.39	0.36	0.27	0.93	0.33	0.20	0.60	0.38	0.26	0.39	0.09	0.08	0.22
800	0.41	0.22	0.40	0.37	0.23	1.13	0.32	0.21	0.56	0.38	0.23	0.37	0.08	0.08	0.26
Current Policy	1.86	0.05	-0.10	0.38	1.43	0.91	-1.16	-1.16	-0.82	2.36	0.16	-0.14	34.33	119.51	449.63

5-A8 Trajectory of the system in V1 (subsidy to renters = 240YUAN)

Step	Outcome Variables					Frequency (out of 100 model runs)				
	Agri-production	Total Income	Pct. Cultivated Area	Pct. Two-Season Rice	Pct. Area Top 10	Agri-production	Total Income	Pct. Cultivated Area	Pct. Two-Season Rice	Pct. Area Top 10
1	2	1	1	-1	1	27	64	41	66	48
2	2	1	1	-1	2	24	63	39	50	46
3	3	1	2	-1	2	24	56	39	49	49
4	3	1	2	2	2	21	62	43	35	50
5	3	1	2	2	2	17	60	41	31	45
6	5	1	2	3	2	20	66	39	33	49
7	5	1	2	3	2	15	66	36	34	42
8	5	1	1	3	2	22	68	38	30	45
9	5	1	2	3	2	20	80	42	27	46
10	4	1	1	3	2	18	73	40	26	48
11	5	1	1	3	2	18	82	39	23	50
12	6	1	2	3	2	19	82	43	28	40
13	6	1	1	2	2	16	77	41	29	46
14	6	1	1	4	2	15	81	40	31	47
15	6	1	2	5	2	25	81	40	23	39
16	4	1	1	4	2	17	81	39	23	45
17	6	1	1	4	2	14	77	39	26	35
18	5	1	1	4	2	16	87	43	28	42
19	5	1	1	4	2	14	81	40	25	46
20	7	1	1	4	2	14	83	40	29	42

5-A9 Trajectory of the system in V2 (subsidy to renters = 240YUAN)

Step	Outcome Variables					Frequency (out of 100 model runs)				
	Agri-production	Total Income	Pct. Cultivated Area	Pct. Two-Season Rice	Pct. Area Top 10	Agri-production	Total Income	Pct. Cultivated Area	Pct. Two-Season Rice	Pct. Area Top 10
1	1	1	1	-1	1	85	85	57	66	81
2	1	1	1	1	1	82	66	64	55	88
3	1	1	1	1	1	68	53	71	44	74
4	2	1	1	1	1	55	58	83	56	61
5	2	1	1	1	1	51	53	78	54	60
6	2	1	1	2	1	58	43	78	51	60
7	2	1	1	2	1	47	44	85	51	51
8	2	1	1	3	2	43	43	84	42	61
9	3	1	1	2	2	47	52	82	44	63
10	3	1	1	2	2	48	45	79	43	64
11	3	1	1	2	2	47	44	74	40	70
12	3	1	1	3	2	48	41	79	44	67
13	3	1	1	3	2	51	43	82	40	72
14	3	1	1	3	2	54	44	76	33	80
15	3	1	1	3	2	53	39	68	37	69
16	3	1	1	3	2	58	40	74	34	78
17	3	1	1	3	2	53	38	74	36	77
18	3	1	1	3	2	50	45	65	35	79
19	3	1	1	3	2	51	48	71	35	78
20	3	1	1	3	2	52	36	60	38	80

5-A10 Trajectory of the system in V3 (subsidy to renters = 240YUAN)

Step	**Outcome Variables**					**Frequency** (out of 100 model runs)				
	Agri-production	Total Income	Pct. Cultivated Area	Pct. Two-Season Rice	Pct. Area Top 10	Agri-production	Total Income	Pct. Cultivated Area	Pct. Two-Season Rice	Pct. Area Top 10
1	1	1	1	1	1	63	64	49	66	50
2	1	1	1	1	1	75	77	58	70	55
3	1	1	1	1	1	78	83	58	74	65
4	1	1	-1	1	1	79	84	67	75	70
5	1	1	1	1	1	84	88	63	84	63
6	1	1	1	1	1	82	84	64	82	75
7	1	1	1	1	1	83	87	69	82	74
8	1	1	1	1	1	89	94	81	87	77
9	1	1	1	1	1	93	90	78	84	76
10	1	1	-1	1	1	90	92	76	77	86
11	1	1	1	1	1	90	92	66	72	78
12	1	1	1	1	1	94	91	74	76	84
13	1	1	1	1	1	96	97	72	76	81
14	1	1	1	1	1	95	89	67	74	79
15	1	1	1	1	1	94	91	78	65	79
16	1	1	1	1	1	96	87	77	66	85
17	1	1	1	1	1	97	85	72	63	84
18	1	1	1	1	1	95	89	77	68	84
19	1	1	1	1	1	94	83	83	63	82
20	1	1	1	1	1	96	85	73	62	82

Chapter VI

Summary, Discussion, and Future Research

Summary

This study generated a number of insights about rural development in PLR amid institutional changes and flood hazards:

(i) Farmer households are economic agents who attempt to increase their economic benefits in an increasingly free-market economy (see Appendix). Though some social and physical factors at the community level (leadership, location, and natural resources) can provide advantages or be disadvantageous for the livelihoods of individual households exposed to the same policy settings and macro processes, the variations in development level among rural households are largely determined by their own characteristics (mainly human and social capital) (Chapter IV).

(ii) Most households, constrained by small farmland holdings, their education levels and skills, the overall development of the industrial sector, and a large amount of rural labor supply, have few feasible options and rely on migratory work as their major income source. Thus, they are unable to raise their income to another level (Chapter IV).

(iii) In the process of Chinese urbanization, the livelihoods and well-being of rural households have been significantly affected by national policies (development and land polices in particular), and the Three Issues of rural development is closely related to the development dynamics of the agricultural and industrial sectors (Chapter IV).

(iv) The current policy of subsidizing rice cultivation may have done little good and some harm for rural development (see Appendix and Chapter V). The policy's largest positive effect seems to be preventing farmer households in places with poor farmland resources from deserting their land by slightly increasing crop cultivation profits from their marginal land. The policy may also have further reduced scales of farming operations across villages, and therefore, the potential of limited farmland may not be fully realized. The policy is unfair because villages with rich farmland resources receive large subsidies in addition to their inherent natural resource advantages, and farmer households in farmland-poor places are left to seek migratory work.

(v) Farmland size is a lever that government policies can use to increase agricultural production and rural household well-being (see Appendix). Current low farmland productivity is associated with the low effort farmer households put into crop cultivation. Farmer households are, in fact, significantly constrained by the availability of farmland resources. The diminished effort they put into crop cultivation is due largely to small farmland holdings, which also contributes to current low farmland productivity by preventing the application of machinery and other innovations (Chapter V).

(vi) The private rental market is efficient enough to match the demand and supply of land-use rights, and no other official market forms are needed (Chapter V). The lack of larger scales of farming operations in rural areas is mainly due to the disincentive of land-use-right leases, which are usually signed for short periods (Chapter V).

(vii) Subsidizing farmer households that rent out their land-use rights for longer terms will likely considerably improve various aspects of the agricultural sector and create a potential for it to expand in most places by increasing scales of framing operations (Chapter V). In villages with poor farmland resources, the subsidy is expected to improve the agricultural sector to a greater degree and improve the economic state of every household. In villages with average farmland resources, because household decisions about long term rental of land-use rights are sensitive to subsidy size, the policy is expected to be more efficient in stimulating the land rental market, as well as increase rural income to a greater degree. These outcomes are expected to be less uncertain.

(viii) In PLR, variations in development level are not correlated with flood risk at either the town level or the household level (Chapter III and Chapter IV). The livelihoods of most farmer households in PLR are not greatly affected by flooding due to large proportions of off-farm income, but poor households are most affected by flooding (Chapter IV). The current agricultural practices appear sensitive to flooding, but the degree to which the agricultural system is affected by flooding varies across villages. Villages with good and rich farmland are major rice production bases which are usually protected by crucial levees, and therefore, the sensitivity of their agricultural production is low. But farmland-poor villages whose agricultural production is also highly sensitive to flooding have a double development disadvantage. They also receive lower subsidies than other villages under the current policy of subsidizing rice cultivation (Chapter V).

(ix) In PLR, the degree of exposure and sensitivity to flooding at the town level is strongly correlated, and exposure is largely associated with the town's distance to the lake (Chapter III). Town's development levels are, however, more associated with the degree of urbanization and distance to cities. The 298 towns in PLR differ largely in their three dimensions of well-being: exposure, sensitivity, and development level.

These insights resulted in the following rural development policy recommendations:

(i) To effectively promote rural development and increase the overall well-being of rural households in PLR and China, the government needs to implement policies to assist farmer households in establishing robust livelihoods via diverse paths: rural-to-urban migration, home-based development, and large-scale farming. While continuing to promote the development of the industrial sector in a way that matches labor quantity and quality, the government also needs to implement appropriate migration policies to encourage migrant workers who thrive in cities to settle in cities. In the agriculture sector, the government needs to implement different land policies to effectively facilitate large scales of farming operations in different locations. The government may subsidize households that rent out land-use rights for longer terms in most places to encourage secure land-use-right exchanges. The government may use subsidy size for long-term renters as an instrument to control land-use-right exchange activities, as well as the degree to which farmland is concentrated in rural areas to keep agricultural sector development synchronized with industrial sector growth. They can also use the subsidy to address inequality in natural resources between villages. To promote local urbanization in rural areas, the government can further exploit the concept of Farmer Associations and focus on building leadership among rural households.

(ii) The government can combine flood-impact-mitigation efforts with development projects to better promote the overall well-being of rural households and address the issue of social and environmental inequity. One fifth of the farmland in PLR is exposed to high flood risk where the agricultural system is sensitive to flooding. In such places, the government may promote new land-use practices to increase land profitability and reduce flood damage. By encouraging family-based larger scale farming operations, the government can help reduce the constraint of small farmland holdings and make new land-use practices feasible. In places with poor farmland resources, the government, by providing larger subsidy sizes to long-term renters, can compensate for their poor natural resources, helping farmer households who wish to specialize in agriculture acquire large areas of farmland at a relatively low cost, as well as assist renters in establishing secure urban livelihoods. In places where the exposure of human life and farmland to natural hazards is extremely high, the government may provide additional assistance to farmer households so they can establish new urban livelihoods and may eventually migrate out of their marginal environment to promote both human and environmental well-being. The government also needs to implement special programs to help extremely poor households break the poverty cycle. Such interventions should increase these families' feasible options, which will also reduce the sensitivity of their livelihoods to flooding.

This study also generated some insights for the towns, villages, and households in PLR about how to increase overall well-being:

(i) Town governments need to have a clear understanding of exposure, sensitivity, and the various aspects of development in their towns. They need to know what and where the problems exist to effectively promote farmer household well-being. While all the towns in PLR need to increase their development level, they each need to make development plans based on their unique situation. Specifically, those towns that are not heavily exposed to flooding but have low levels of development may examine their social systems for ways to increase their future development level. Those places with degrees of sensitivity greater than exposure should examine their development patterns carefully to further reduce sensitivity. And those towns that have high levels of development and high degrees of exposure and sensitivity need to pay particular attention to engineering works (i.e., levees) in addition to making appropriate adjustments to development. To increase overall human well-being, all town governments need to look at the broader aspects of development beyond pure economic measures.

(ii) Villages need to develop in accordance with their own characteristics. Specifically, those villages endowed with special kinds of natural resources need to look ahead and invest their accumulated capital in developing other livelihoods to achieve sustained development. Those villages with strong farmland resources need to further increase land-use efficiency to fully realize their farmland's potential. Villages with poor natural resources and high exposure may take advantage of the urbanization process to migrate out with the assistance of the government. All villages, except those with extremely high exposure, need to take advantage of their uniqueness in natural environment, location, culture, or social capital to create high-return livelihood options that complement one another and also integrate agriculture.

(iii) Individual households need to consider their own characteristics, the characteristics of their villages, and their natural environment to decide which livelihood profile is more appropriate for them. Each of the four livelihoods profiles (diversified near-home livelihood profile, business-oriented livelihood profile, farming-based livelihood profile, and migratory work and farming combined livelihood profile) can produce higher levels of development. But they require certain household characteristics, and some are facilitated by external conditions. For most households that rely on migratory work as their major income source, investing in education and skills will improve their competitiveness in urban job markets and produce long-term economic returns. As the industrial sector upgrades gradually from labor intensive industries to technology, information, and service oriented industries, rural labor needs to keep pace. Rural households also need to pay attention to collaborative efforts because individually they are much less capable of overcoming the constraints at both the individual and macro levels. A village's social capital significantly shapes individual household livelihood but is also shaped by individual household's human and social capital.

Discussion

Combining research methods

This study demonstrated the usefulness and importance of combining multiple methods in understanding how social, environmental, and individual heterogeneities and their complex interactions shape human well-being. These analyses also complement one another to provide useful information for guiding sustainable development in the real world. While large-scale assessment (combining GIS, remote sensing, and socio-economic data) provides policy makers with information about variations in various aspects of development across a region, a micro-level look at the decisions and actions of individual households (using surveys and interviews) can yield in-depth understanding about the root causes of these system outcomes. Understanding these root causes can help policy-makers design policies that effectively improve macro processes and eliminate constraints for households to increase their overall well-being. Built upon empirical analyses, agent-based models can be used to quantitatively assess the impacts of each component of CHES and explore the potential effects of designed policies. Thus, they provide additional insights about where the problems are, and how we may induce the system to move toward more desirable states. These three kinds of analyses are all important.

Agent-based modeling

This study demonstrated that agent-based modeling can generate new, useful, and convincing insights about a CHES, if built upon a good understanding of the system.

When designing and building ABMs, it is important to know how agents are diverse, and what interactions and feedbacks exist in a system. A major strength of agent-based modeling is its ability to capture agent diversity, interactions between agents, and the feedback between individual behaviors and global states. This is also why ABMs may generate *new* insights about a system. In this study, the model sheds new lights on the effects of the current policy. It may not only have limited effects in promoting rural development (as shown by the household analyses), but may also produce several undesired effects. By providing quantitative assessments of the constraints of farmland resources and the performance of the land rental market, the model also generated additional insights regarding why farmer households put low effort into crop cultivation and why rural areas lack large scale farming operations.

A model is, by definition, an abstraction of a system. An important goal of modeling is to generate *useful* insights about a system, not to simulate a system in detail. This study, using a simple model that simulates farmer households in different kinds of places with different endowments in farmland resources, generated a number of useful insights for future economic development and regarding social fairness, which could not be obtained by realistically simulating all (and therefore, a large number of) agents in the entire region.

To generate *convincing* insights, a model must build upon empirical studies, but empirical data may be better used to guide model building rather than to be matched precisely. In this study, I developed the model based on my understanding of the system (particularly the decisions of households) acquired from the analyses of household surveys and interviews. At the micro level, I used survey data to calibrate and initialize the model when it was applicable. At the macro level, I validated the model by comparing model outcomes with empirical data in three villages in relative values and general trends in land-use change. I also tested the modeled behavior of the land rental market, which appears consistent with what the economic theory of price would suggest. All these efforts have increased the confidence level of the model results. The confidence level of the model results is also increased if they can be intuitively explained so that people who have experiences with the system can see why the results are plausible.

Modeling is not only a technique, but also an art. The art is to capture the essence of a system, as a painter captures the spirit of an object with a few strokes. Modelers, like the artist, must decide what details to include and how to execute them. Those who are dubious about agent-based modeling or modeling in general have a reason: there are painters who paint every fine detail to which we are so attracted and get lost. And there are also painters in whose few strokes we cannot recognize the object. Modeling can be useful if we do it right. After all, there are impressionist painting masters, but none of them imagined their paintings in their heads: they all observed reality intensely.

The science of complexity and CHES

This study demonstrated that the perspective of CHES is important for the study of sustainability, and the science of complexity can provide theoretical grounding for the study of CHES. Guided by the science of complexity, the new sustainability framework provides a way of looking at CHES that integrates social, economic, institutional, and environmental perspectives, while focusing on the underlying processes and the dynamics of such systems. By providing ways of looking at the world, frameworks guide us to understand the world. To a certain degree, a framework determines what questions we ask, how we answer the questions, what answers we get, and how we may change the world based on our understanding. A framework should also be simple enough to be implemented. The case study in PLR has demonstrated the usefulness of the new sustainability framework by generating rich insights about rural development amid institutional changes and flood hazards, which could not be obtained by studying the social, economic, institutional, or environmental components separately.

The basic idea of the framework is: (i) use multiple variables to represent and access the well-being of a system (though the variables may be chosen differently to reflect the nature of the system or the major concerns); (ii) understand how the actions and interactions of human agents, the biophysical processes, and the interactions between the human system and the natural system shape well-being and drive state change; and then (iii) explore how to induce the system to desired states accordingly.

This basic idea may be applicable to the developed world as well. Whereas less-developed places need to increase their development level in a sustainable way, the major task for developed places is to make adjustments to their current development. Yet the analyses may focus more on the causes of the unsustainable trend. Though the pathways can be different, both developed and less developed places need to anticipate future changes, make development plans, and design policies based on periodical scientific assessments and causal analyses that reflect constant social and environmental changes and the new dynamics of the system to effectively and gradually shape the system toward sustainability.

New questions and remaining challenges

This study only made a small step forward in the study of sustainability. Significant challenges exist both for developing and developed economies in other dimensions of sustainability: land use, natural resources, energy, pollution, and human health. New questions are also raised from this study about development in the less developed world. For example, how should polices adapt over time to suit the new development dynamics of the agricultural and industrial sectors to promote economic growth and human well-being? How can less developed places do better to make a transition to the developed world in the interconnected world system? These challenges and questions beg for more general analyses of sustainability at both local and global scales.

Future research

In this section, I propose a general framework of sustainability, some broad research questions, and approaches for future research. The overall objective is to understand the fundamental processes underlying sustainability at both local and global levels. And I continue to use the science of complexity to guide the study of CHES, for I believe using complex systems' approaches to study CHES can open up new horizons and new lines of research that lead to important new understandings of sustainability.

A general framework of sustainability

The framework is based on the analysis of long-term economic growth, looks at multiple dimensions of human and environmental well-being, treats the environment as an endogenous entity, and examines the interconnectedness between places (Figure 6-1a; Figure 6-1b). It views scales, beyond the traditional geographical definition, as networks of interacting CHES.

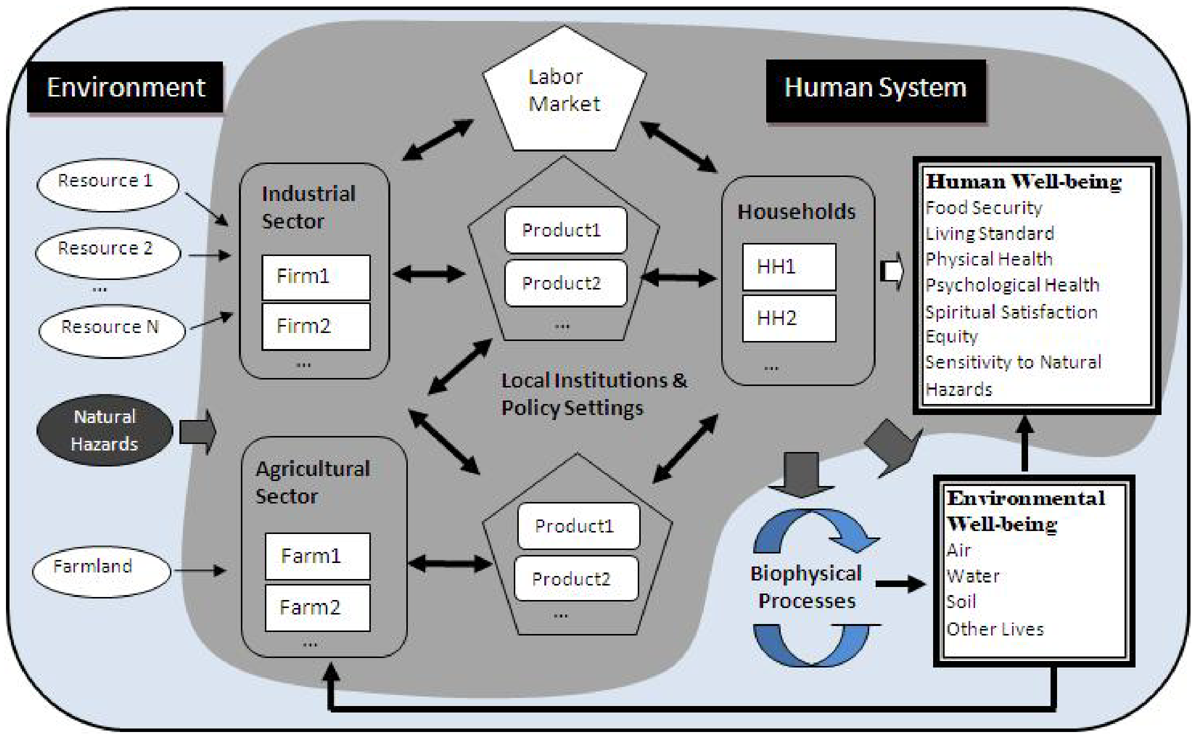


Figure 6-1a A general framework of sustainability: local places.

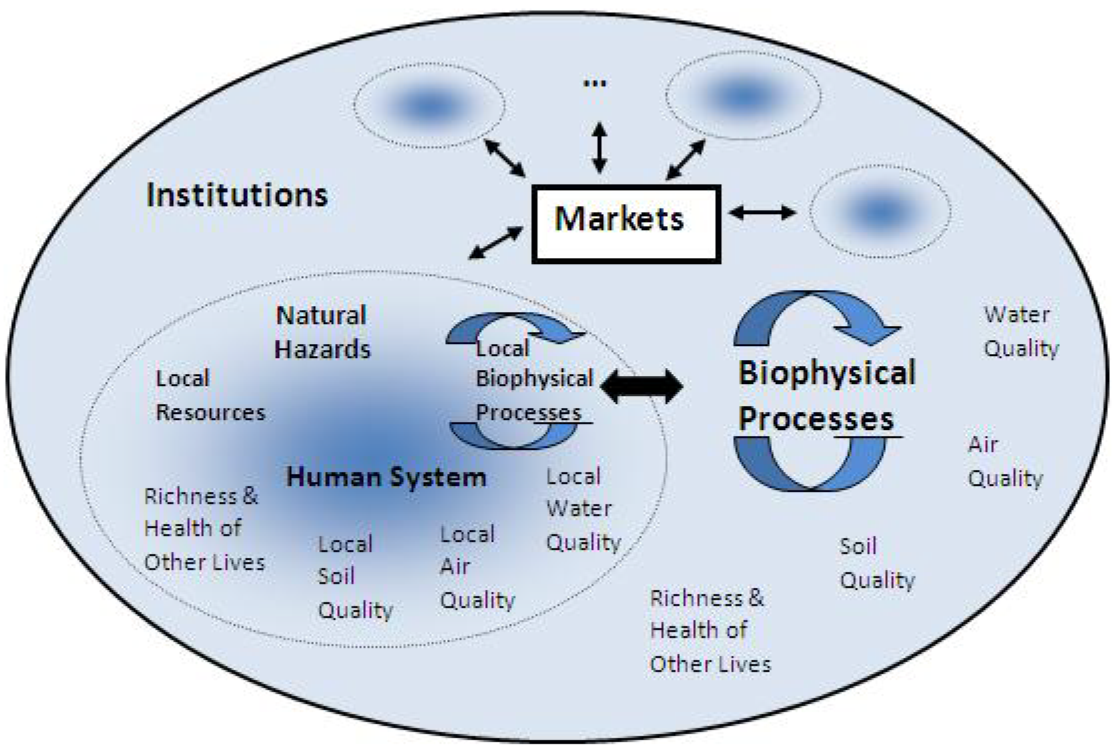


Figure 6-1b A general framework of sustainability: linkages between places.

Global constraints:

- Farmland and natural resources of each kind are limited at a given time.

At local places and the diversity of places:

- Farmland and other natural resources are limited with some shrinking over time.
- Each place has its own characteristics in terms of geography, natural resources, institutional and cultural settings, technologies, development history, and human resources (including population size and growth and labor productivity).
- Technologies determine the efficiency of production.
- Production and consumption have environmental impacts.

Major feedback:

- Degraded environmental well-being affects human well-being (e.g., human health and spiritual satisfaction) and production (e.g., degraded soils reduce agricultural output).

Linkages between local and global effects:

- Environmental impacts can spread from local places to larger areas and affect global environmental well-being and human well-being in other places.
- Places can trade production materials and products, but due to global constraints, how locales use natural resources can affect human well-being at the global level.
- The same kind of natural resources can be used to produce different kinds of products and contribute to human well-being in different dimensions, sometimes increasing human well-being in one dimension in some places, and decreasing human well-being in another dimension in other places (e.g., using local farmland to grow corn for ethanol fuel affects global food security).

Trade-offs:

- Between present and future economic growth
- Between human well-being and environmental well-being
- Between different dimensions of human well-being
- Between local and global interests

- ➢ Between different ways of spending accumulated capital: consumption, reducing environmental impacts, and investing in research, technology and innovation

LOCAL Sustainability:

Human well-being in a local place achieves a certain level and continues for many generations (forever, theoretically).

GLOBAL Sustainability:

Human well-being in every place achieves a certain level and continues for many generations (forever, theoretically).

Broad research questions

Under this framework, we can ask many important questions that will guide us to understand the fundamental processes underlying sustainability. By understanding the fundamental processes, we may be able to appropriately decide the trade-offs, which is identified as a challenge of sustainability science (Levin and Clark 2010). The following are only a few of those questions:

❖ *How do various factors and forces (geography, natural resources, institutions, cultures, technologies, and trade etc.) interact with one another through the decisions and actions of individual households and firms to drive long-term economic growth in a given place? What are the mechanisms through which innovations promote growth?* Like Robert Lucas Jr. (2004) who finds it "hard to think about something else," many economists, from Adam Smith (1976) to Sir Arthur Lewis (1954), Robert Solow (1956), Paul Romer (1986), Robert Barro (1998), Jeffery Sachs (1997), William Easterly (2001), Daron Acemoğlu (2002), and Justin Yifu Lin (2009)… have pondered over and advanced our understanding of the causes of economic growth from various perspectives. Nonetheless, developing countries are largely unsuccessful in making the transition to developed country, while developed economies face other problems, such as financial crises and a slowdown in growth. Most current economic studies focus on one or some factors and use econometrics to analyze their effects quantitatively. Because economic growth is an outcome of the *interplay* of many factors and forces and is path-dependent (Arthur 1994 and 1997; Nelson 1995), using a complex system's approach to examine interactions and development history is important and will generate new insights about the fundamental *processes* of economic growth.

Along this line, another interesting and important question is: *Can less developed places catch up with developed places in the interconnected world?* The Dependency Theory (which argues that "poor states are impoverished and rich ones enriched by the way poor states are integrated into the world system") (Kláren 1986; So 1990) suggests that the answer is "no." The economic development of "Four Small Dragons" in Asia (Hong Kong, Singapore, South Korea and Tai Wan), and Justin Yifu Lin's sector-based economic models suggest that they may be able to catch up. A complex system's approach can help better examine economic development in less developed places in a *global context*.

❖ *How do different ways of using resources at local places affect local and global sustainability? Which local development strategies and global institutions facilitate local and global sustainability? Is local sustainability attainable without global sustainability?* A complex system's approach facilitates exploring global consequences of local actions. In addition, there are "lever points" in complex systems that can produce large changes with a small amount of intervention (Holland 1995 and 1998; Mitchell 2009). Using a complex system's approach, we may find such levers in CHES and use them to design policies to *induce* individual behaviors that collectively lead to desired outcomes.

❖ *What could lead to disastrous future outcomes? And how can we avoid these elements?* The state space of complex systems is large, and there are "tipping points" where a system would experience sudden state transition (Schelling 1972; Holling 1973; Luenberger 1979; Folke 2006; Bramson 2009). Using a complex system's approach, we can identify conditions that lead to un-sustainability or "tipping points," where CHES could shift to an undesired state. Identifying these conditions will provide a better chance to avoid a disastrous future.

Because the majority of the world population will be living in urban areas, urban development is particularly important for achieving sustainability. Urbanization is proceeding rapidly, especially in developing nations. *How to proceed with urbanization and how to develop cities* is crucial to a sustainable future. Driven by and desperate for growth, large cities grow into "mega-cities," and cities in the developing world are struggling to become “global cities” guided by “master plans,” which, in many cases, ignore local characteristics and place too much emphasis on external forces (Chakravorty 1996; Robinson 2002; Marshall 2003; McKinsey and Company 2009; Ilesanmi 2010). And the implications of the development of mega-cities and global cities on people’s lives, environment, and governance are not well understood. Urbanization and urban development involves the actions and interactions of many human agents. A complex system’s approach can help better evaluate the consequences of urbanization’s different paths, as well as various urban planning approaches. Cities have their intricate inner workings, and the diversity in uses of neighborhood buildings and land is fundamental to a vital economy, healthy social life, and even the safety of human life (Jacob 1961 and 1968; Holston 1999). Using a complex system’s approach, we may be able to develop guidelines for urban development such that many human agents collectively make better cities that are economically vital, environmentally and people friendly, and adaptable than master planning does.

Approaches

This line of sustainability research needs *empirical studies* and *synthesis*. While in-depth case studies that examine the co-evolution of the natural environment, human behaviors, cultures, institutions, and development in CHES can provide empirical understanding about the processes underlying human and environmental well-being, agent-based and network models, built upon empirical understanding and relevant theories, can be used to explore the interactions between agents and between places, as well as the feedback between local and global effects. Insights generated from models can also guide the direction of empirical work. This iterative procedure of empirical work and modeling will help us better understand the fundamental processes underlying local and global sustainability.

This line of sustainability research can build upon the work of *agent-based computational economics* (ACE). Integrating evolutionary economics, cognitive science, and computer science, ACE studies and models economic processes as dynamic systems of interacting agents (Tesfatsion and Judd 2006; Gintis 2007; Deissenberg et al. 2008; Mandel et al. 2009).

Future work in PLR

Several important questions about rural development in PLR have not been answered by this dissertation.

(i) *How may the land rental market respond to different scenarios of future changes? How can government policies better adapt over time to promote rural development*? Major future changes include increasing wages for migrant workers, decreasing farmland area, and increasing farmland productivity. There has been a decline in farmland due to industrial and urban residential use in China. The industrial sector's growth and the agricultural sector's productivity play a central role in economic growth dynamics in less developed countries. Some initial experiments with the existing model suggest that land-use-right prices rise as total farmland area decreases, fall as the average wage for migrant workers increases, and rise as farmland productivity increases. These relationships require further investigation because some appear to be nonlinear and may have thresholds and policy implications. This dissertation has demonstrated how policies should vary across places taking into consideration social and environmental variations. Policies, however, also need to anticipate change and change based on new dynamics to effectively promote development. For instance, as migrant workers' wages increase, subsidizing rice growers may become necessary, though this currently does little good for rural development. This question can be addressed by introducing game dynamics into the agent-based model.

(ii) *How may the agricultural sector be affected by social and environmental shocks? i.e., will rural development be resilient?* Social shocks can be a sudden recession in the industrial sector or price changes in the world agricultural product market, while the major environmental change is flood dynamics. Each of these shocks can exhibit different levels of magnitude and remain for different lengths of time. This dissertation has demonstrated that rural development in China is tightly linked to the industrial sector, and the current agricultural production system in PLR is sensitive to flooding. And when a recession occurs in the industrial sector, migrant workers are affected first. Therefore, it is important to further examine the impact of these social and environmental shocks on rural development. This question can be addressed by combining the agent-based model with mathematics to analyze the system's state transition.

(iii) *To what degree does the spatial land-use pattern in PLR conform to what the decision-making model suggests?* This dissertation has demonstrated that the spatial patterns of land-use in PLR are largely defined by the biophysical environment, shaped by location relative to urban centers, and finely tuned at the micro level by household characteristics. As a result, the landscape in PLR is a mosaic of rice, cotton, and vegetables, with one-season rice in low-lying areas and patches of other minor crops in hilly areas. In general, we are more likely to see vegetable fields near urban centers. We expect to see more rice paddies first (mostly one-season rice with the exception of two-season rice in areas that are major bases for agricultural production), and then an increase in cotton fields at greater distances from these centers. Individual household characteristics modify this broad pattern at the micro level by affecting the proportions of cotton and rice. This land-use spatial pattern projected by the household decision-making model can be tested using geo-statistics and combining Landsat satellite images and high-resolution satellite images.

(iv) *Why have some villages with similar natural environments adopted different economies and followed different paths?* Through this dissertation work, I have identified two villages that have similar physical environments but have adopted different economies and followed different development paths. One of them is still traditional, while the other is modern with an enterprise and corporate management. A closer look at these villages using an ethnographic approach and examining their development histories will provide an empirical understanding about how the co-evolution of the natural environment, human behaviors, cultures, institutions, and development shapes human and environmental well-being on the ground.

(v) It will also be interesting to compare standard economic approaches with agent-based modeling. How can I frame the four questions addressed in Chapter V under the standard economic framework? Will standard economic approaches generate different, more, or fewer insights than the agent-based model? And what are the differences, strengths, and weaknesses of the two approaches?

References

Levin, S. A. and Clark, W. C. (2010) Toward a science of sustainability, CID (Center for International Development) working paper No. 196. Harvard University, Cambridge, MA. Available at http://www.hks.harvard.edu/centers/cid/publications/faculty-working-papers/cid-working-paper-no.-196.

Smith, A. (1976) *The Wealth of Nations.* University of Chicago Press, Chicago.

Lewis, W. A. (1954) Economic development with unlimited supplies of labor. *Manchester School of Economic and Social Studies* 22:139–91.

Solow, R. (1956) A contribution to the theory of economic growth. *Quarterly Journal of Economics* 70(1):65–94.

Romer, P. M. (1986) Increasing returns and long-run growth. *Journal of Political Economy* 94(5):1002–37.

Lucas, R. E., Jr. (2004) *Lectures on Economic Growth*. Harvard University Press.

Lin, J. Y. (2009) *Economic Development and Transition: Thought, Strategy, and Viability*. Cambridge University Press, Cambridge, UK.

Acemoglu, D., Johnson, S. and Robinson, J. A. (2002) Reversal of fortune: Geography and institutions in the making of the modern world income distribution. *The Quarterly Journal of Economics* 117(4):1231–1294.

Sachs, J. D. and Warner, A. M. (1997) Fundamental Sources of Long-Run Growth. *The American Economic Review* 87(2):184–188.

Easterly, W. R. (2001) *The Elusive Quest for Growth: Economists' Adventures and Misadventures in the Tropics*. MIT Press, Cambridge, MA.

Barro, R. J. (1998) *Determinants of Economic Growth: A Cross-Country Empirical Study*. MIT Press, Cambridge, MA.

Arthur, B. (1994) *Increasing Returns and Path Dependence in the Economy*. University of Michigan Press, Ann Arbor, MI.

Arthur, B. (1997) *The Economy as an Evolving Complex System II*, edited with Steven Durlauf and David Lane, Addison-Wesley, Reading, MA, Series in the Sciences of Complexity.

Nelson, R. (1995) Recent evolutionary theorizing about economic change. J*ournal of Economic Literature* 33(1):48-90.

Kláren, P. F. (1986) Lost promise: explaining Latin America underdevelopment. In: *Promise of Development, Theories of Change in Latin America* (eds.) Klaren, P. F. and Bossert, T. Westview Press, Boulder, CO.

So, A. Y. (1990) *Social Change and Development: Modernization, Dependency and World-System Theories*. Sage, Newbury Park, CA.

Holland, J. H. (1995) *Hidden Order: How Adaptation Builds Complexity*. Perseus Books, Cambridge, MA.

Holland, J. H. (1998) *Emergence: From Chaos to Order*. Perseus Books, Cambridge, MA.

Mitchell, M. (2009) *Complexity: A Guided Tour*. Oxford University Press, New York.

Holling, C. S. (1973) Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst*. 4:1–23.

Schelling, T. C. (1971) Dynamic models of segregation. *Journal of Mathematical Sociology* 1 (2):143–186.

Luenberger, D. G. (1979) *Introduction to Dynamic Systems: Theory, Models, and Applications*. John Wiley and Sons, New York.

Folke, C. (2006) Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change* 16:253–267.

Bramson, A. L. (2009) Formal measures of dynamical properties: Tipping points. *AAAI Technical Report* FS-09(3):2-11.

Chakravorty, S. (1996) Too little, in the wrong places? Mega city programme and efficiency and equity in Indian urbanization. *Economic and Political Weekly* 31 (35/37): 2565-2567+2569-2572.

Robinson, J. (2002) Global and world cities: a view from off the map. *International Journal of Urban and Regional Research* 26: 531–554.

Marshall, R. (2003) *Emerging Urbanity: Global Urban Projects in the Asia Pacific Rim.* Routledge, London. Ch. 8: Doi Moi and the Ascending Dragons of Vietnam: Hanoi North and Saigon South, pp. 120-148.

McKinsey and Company (2009) *Preparing for China's Urban Billion*. Available at: http://www.mckinsey.com/mgi/publications/china_urban_billion.

Ilesanmi, A.O. (2010) Urban sustainability in the context of Lagos mega-city. *Journal of Geography and Regional Planning* 3(10):240-252.

Jacob, J. (1961) The Death and Life of Great American Cities. Vintage Books, New York.

Jacob, J. (1968) The Economy of Cities. Vintage Books, New York.

Holston, J. (1999) The modernist city and the death of the street. In Low, S. (ed.) *Theorizing the City: The New Urban Anthropology Reader.* Rutgers University Press, New Brunswick, pp. 245-275.

Tesfatsion, L. and Judd, K. L. (eds.) (2006) *Handbook of Computational Economics, Vol. 2: Agent-Based Computational Economics*, Handbooks in Economics Series, Elsevier/North-Holland, Amsterdam.

Gintis, H. (2007) The Dynamics of General Equilibrium. *The Economic Journal* 117:1280–1309.

Deissenberg, C., Van der Hoog, S. and Dawid, H. (2008) EURACE: A massively parallel agent-based model of the European economy. *Applied Mathematics and Computation* 204:541–552.

Mandel, A., Furst, S. Lass, W., Meissner, F. and Jaeger, C. (2009) Lagom generiC: An agent-based model of growing economies. ECF(European Climate Forum) working paper. Available at http://www.diva-model.net/fileadmin/ecf-documents/publications/ecf-working-papers/mandel-fuerst-lass-meissner-jaeger__ecf-working-paper_2009-01.pdf.

Appendix

Understanding the Mechanism underlying Land Use and Land-use Change

Introduction

In this section, I present an analysis of the land-use system to understand the mechanism underlying spatial patterns and temporal changes in agricultural land use in PLR by analyzing land-use decisions of rural households in the large social, economic, institutional, and environmental context. Because household land-use decisions are part of their overall livelihood strategies, this analysis also complements the analysis of household well-being presented in Chapter Four. I present this analysis as an appendix because it does not fall into the sustainability framework.

Land use involves human motivations, decisions and activities on a landscape, resulting from interactions between human activities and the environment. Land covers worldwide are dramatically changed by human use of land (Allen and Barnes 1985; Turner et al. 1990; Whitby 1992), and therefore understanding the social, economic, institutional and cultural drivers of land-use/land-cover change (LUCC) has been an important part of global change research (Turner II, Ross, and Skole 1993; Turner II et al. 1995; Lambin et al. 2001; Geist and Lambin 2002). Though significant progress has been made in LUCC research in the past decade, the complexity of land-use systems is still not well understood (Overmars and Verburg 2005; Lambin and Geist 2006).

Two approaches remain central in studying the underlying causes of LUCC. While the mainstream geographical approach emphasizes the importance of biophysical suitability, land-use studies rooted in the social sciences focus more on the factors that influence land-use decisions at the household level (Overmars and Verburg 2005). To identify factors that influence individual land-use decisions, household surveys are often conducted and analyzed quantitatively (Perz 2001; Walker et al. 2002; Pan and Bilsborrow 2005; Overmars and Verburg 2006). Narratives are sometimes used to account for the historical context in theorizing LUCC (Walker and Solecki 2004). Farmar-Bowers and Lane (2009) conducted in-depth interviews of farmers to understand their decision-making process and generate insights for policy development.

Various schools of thought have contributed to the theoretical understanding of land use. One line of research (Alonso 1964; Chomitz and Gray 1996; Walker 2004; Nelson 2002) elaborates on the model of von Thünen (1966), and the basic insight is that location and transport cost are important in determining farmer decisions and land use. Another line of research has developed from the model of Chayanov (which Chayanov used to explain land-use practices after the 1917 Revolution in Russia), and focuses on the importance of household life cycles on land use (Walker and Homma 1996; McCracken et al. 1999; Perz 2001; Perz and Walker 2002).

In studying land-use systems as complex adaptive systems, and synthesizing multiple perspectives from the current land-use science, I look at land-use variations across three dimensions of space, time and individual household behaviors, and explain them as collective outcomes of decisions and actions of individual households interacting with the natural environment within the large social-economic-political settings (Figure 1). Combining quantitative and qualitative data and methods, I analyzed land-use variations in the Poyang Lake Region (PLR) of China across these three dimensions, and examined the land-use and livelihood decision-making processes of households to demonstrate how various factors and forces at multiple levels from the human system and the environment interact with the characteristics of households shaping land use and driving land-use change.

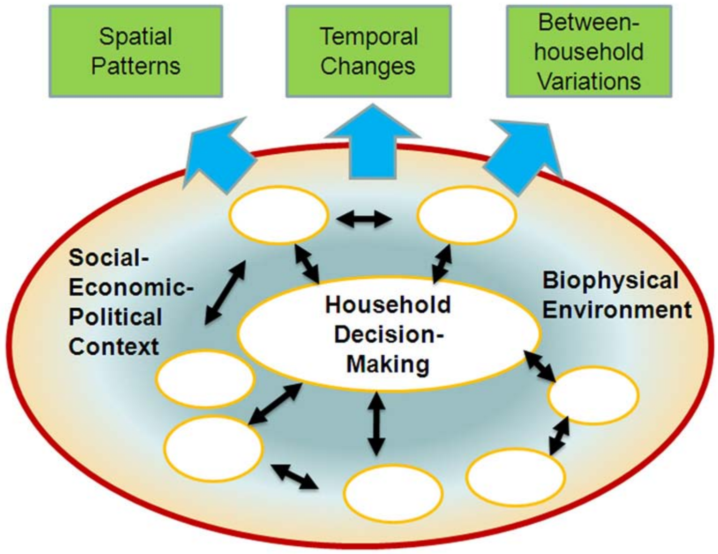


Figure 1 Analysis framework: Land-use systems as complex adaptive systems.

A total of 197 households in eight villages of different types were surveyed, and 69 farmer households, village leaders and local government officials were interviewed with open-ended questions. Based on the analysis, I discuss some policy implications regarding promoting agricultural production.

Study area and policy context

PLR (Figure 2) is largely a rural area in Jiangxi Province that includes ten counties and two cities (Nanchang and Jiujiang) with a total area of 20,970km^2. According to the Chinese Census in 2000, the total population in PLR was about 7.7M, and 76% of the households in PLR, excluding the two cities, were classified as rural. PLR is a major agricultural production base. According to the Jiangxi Statistic Year Book 2005, PLR produced 19.08％, 32.47％ and 34.86% of the total grain, cotton and aquaculture products in Jiangxi Province in 2004. Rice cultivation has traditionally dominated, and is still the major agricultural practice in PLR. Rice can grow once a year from mid or late June to early October, called one-season rice, or it can be double-cropped, i.e., after a first crop of early rice is planted in late April and harvested in mid July, a second crop of late rice is planted in mid or late July and harvested in late October or early November.

Cotton is usually planted in May and harvested from October till the end of the year. As an upland crop, cotton can better tolerate dry conditions than rice. Other agricultural products include rapeseed, sweet potato and peanut. Rapeseed is usually planted on rice paddies or cotton fields after rice or cotton is harvested, and grows throughout the winter season. The agricultural practices in PLR have been shaped by its physical environment, a floodplain of the largest fresh water lake in China. They are also subjected to flooding from Poyang Lake, which is a well-known hazard in PLR (Zhao and Guo 2001; Huang and Dai 2004; Jiang et al. 2008).

As other rural areas in China, PLR has been experiencing rapid and dramatic social-economic-political changes due to policy reforms at the national level. After 1949 and prior to policy reforms in the late 1970s, the development policies in China had focused on heavy industries under strong central planning (Zhang and Zhang 2005; Hui and Huo 2007; Lin 2009). To support industrial development, prices for agricultural products were fixed at low levels, and production quotas were assigned to local governments. To increase agricultural production, communal farming systems were in place from 1966 to 1978. Also because heavy industries had no need for large amounts of labor, rural residents were not permitted to migrate to urban areas. Migration was controlled by the household registration system (called Hukou), which differentiates urban and rural households. As a result, the gap in development level and living standards between rural and urban areas grew. To promote agricultural production and rural development, the Chinese government began a series of policy reforms in the late 1970s, which shifted production decisions to households and liberalized agricultural markets.

The policy reforms regarding agricultural markets were carried out gradually in several stages (Heerink et al. 2005). The period from 1978 to1984 saw the initiation of the Household Responsibility System, in which the commune system was dismantled, and farmland was contracted out to farmer households in leases (up to 30 years). Prices for agricultural products were increased to encourage agricultural production, and a small portion of the production that exceeded a quota was allowed to be sold at higher but controlled prices. The period from 1985 to 1993 saw a decrease in the state control on marketing and purchasing agricultural products. A dual price system was established for major products like grain, oil-bearing crops and pork, in which prices were fixed for the procurement quota while surplus production was allowed to be sold at market prices or negotiated contract prices. In 1993, procurement quotas were reduced, and in some regions even eliminated. In this period, other products such as fruits and aquatic products were freely traded on the market. The period from 1994 to 2003 marked the re-introduction of a government procurement system for grain as maintaining grain production and securing affordable food supplies became a priority for the Chinese government. Grain prices were raised even higher than world market prices to promote grain production, and the government spent a large amount of money in subsidizing grain procurement, export and storage. The Governor's Grain Bag Responsibility System was implemented, which gave provincial and local governments responsibility for agricultural production to ensure food self-sufficiency at the provincial level. The growth of the industrial sector, resulting from economic reforms, also created labor demand in urban areas. Beginning in 1991, the government has liberalized urban jobs and implemented housing policies that encourage rural-to-urban migration. Beginning in 2004, to further promote grain production, raise rural income, and to be more in line with World Trade Organization (WTO) regulations, agriculture taxes were eliminated. Since then, subsidies have been made to households that produce grains and for high-quality grain seeds and machinery, public investments in rural infrastructure have been increased, and off-farm work opportunities have been further stimulated. Other studies (Zhou and Huang 2003; Heerink et al. 2005; Jiang et al. 2008) have found that these policy reforms have had a great impact on land use and agricultural production in PLR, and I explore these effects further in the context of how household decision making affects spatial, temporal, and household-level variations in land-use outcomes.

Data and methods

I combined quantitative data collected from household surveys with qualitative information obtained from interviews and observations to examine the differences in land use across villages and compared the natural environments, locations and other characteristics of the villages to explain these differences. I combined interviews of farmers and local government officials to identify major temporal changes in land use and the driving forces for these changes. I used multilevel models to analyze what factors (including the biophysical properties of plots, characteristics of households and village location) are associated with land-use choices on individual plots, and combined qualitative information to interpret the results. I then used interviews to understand the land-use and livelihood decision-making process of households and demonstrate how the social and biophysical factors I indentified from the previous analyses interact with each other to shape land use patterns and drive land-use change through the decisions and actions of individual households.

Survey village selection

For the surveyed villages to represent various types of human and natural environments in PLR, the villages around Poyang Lake were stratified by variables representing the natural environment and location relative to urban centers. Eight villages were chosen from a total of 359 villages that are within 12km distance of the lake and on the west side of the lake.

Elevation was used to capture the variations in the natural environment because it is an important environmental feature affecting land use and flood risk in PLR. Throughout history, levees have been constructed to reclaim farmland and protect lives and properties of the residents around Poyang Lake. They affect land use and flood risk by altering the natural terrain. To account for the effects of levees, a digital elevation model (DEM) was adjusted with GIS data that represent levee location and height. Locations in the modified DEM were assigned the height of the levee that protects it or the DEM elevation, whichever was higher. Villages were classified into two types based on adjusted elevations: high elevation (and low risk) and low elevation (and high risk).

Distance to the county capital was used to represent the location of a village relative to urban centers. In China, county capitals are consistently much larger than other towns in the county, and serve as the center of economic and administrative activities for the county. Villages were classified into two types: close to city (within 5km) and far from city (beyond 5km).

Adjusted elevation and distance to county capital formed a two-by-two matrix from which four types of villages were identified and six candidate villages of each type were randomly selected. Information about production structure, migration labor, income per capita, farmland per capita, number of households and population of these villages was then collected through field trips. Based on this information, two villages of each type were chosen, for a total of eight villages. Due to road construction at the time of survey, three pre-selected villages were replaced by other nearby villages that had similar characteristics to the originally selected villages (Figure 2).

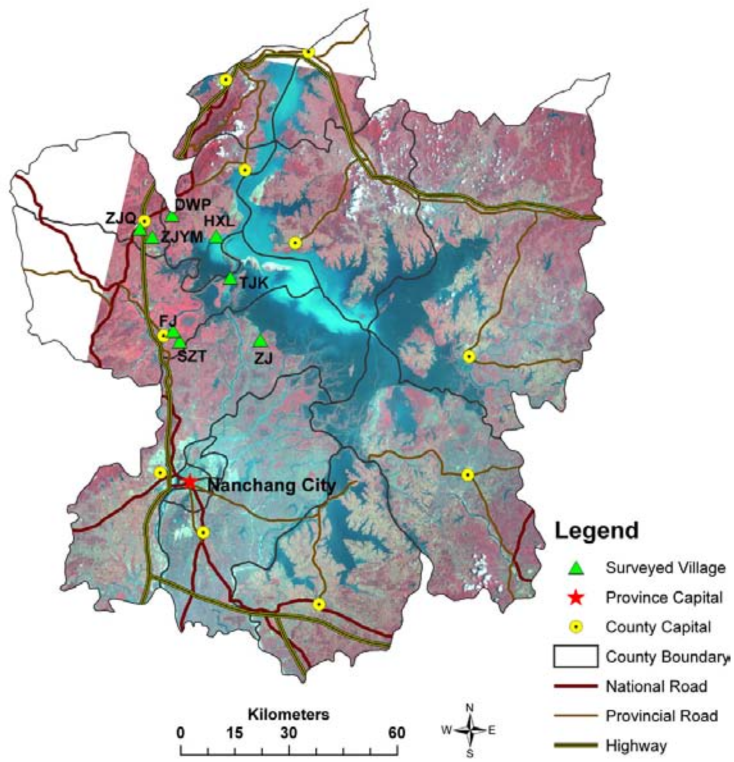


Figure 2 The Poyang Lake Region and surveyed villages.

Household surveys

Surveys were field tested in the summer of 2006, then conducted orally in January 2007, just before the Spring Festival[1], in order to increase chances that houses would be occupied. Twenty-five percent of the households in each village were randomly chosen for survey (Table 1). Due to availability of households at the time of survey, the actual proportion of surveyed households in each village was slightly different from twenty-five percent.

Table 1 General information of the surveyed villages

Variable Name	ZJ	TJK	FJ	SZT	ZJYM	ZJQ	DWP	HXL
Number of Households Surveyed	23	20	23	19	21	19	35	33
Number of Households Interviewed	13(3)	15 (2)	2	3	5 (1)	3(1)	3(1)	15(2)
Close to County Capital	N	N	Y	Y	Y	Y	N	N
Collective Irrigation System	Y	N	N	N	N	N	Low	Low
Number of Private Pumps	2	0	2	0	1	13	0	1
Average Area per Capita (mu)	2.9	0.6	1.4	1.9	1.7	1.2	0.9	0.6
Average Plot Size	1.2	0.9	0.8	0.8	0.6	1	0.7	0.5
Percent of Hilly Area (%)	0	17	0	0	24	0	0	33
Number of Off-farm Jobs per Household	0.57	1.38	1.488	1.72	1.5	0.90	1.37	2.2
Percent of Off-farm Income (%)	47.62	89.58	72.42	51.37	82.83	48.84	57.72	76.58

The surveys produced data about land use at the plot, household and village levels (Table 2; Figure 3). Data on land-use type, production and biophysical properties were collected at the plot level. Demographic information, farmland endowment, education, social connections (in terms of government contacts) and income sources were collected at the household level or summarized from household member activities and productions from all the plots. Households with incomplete data were excluded from the dataset for this analysis. All continuous variables were mean-centered for statistical analyses.

Table 2 Description of variables used in the multilevel regression analysis

Variable Name	Description	Min	Max	Mean	SD	Frequency
Dependent variable at the plot level (N=1117)						
One-season rice	1 if one-season rice, 0 otherwise					1: 464 0: 653
Cotton	1 if cotton, 0 otherwise					1: 343 0: 774
Independent variables at the plot level (N=1117)						
PlotSize (mu)	The size of the plot	0.02	7.00	0.67	0.59	
Fertility	1 fertility of the soil is good, 2 average, 3 bad					1: 131 2: 676 3: 310
Slope	1 if flat, 2 if hilly					1: 916 2: 201
Distance (minute)	The time it takes to walk to the plot from the house	0	90	14.56	11.04	
Independent variables at the household level (N= 123)						
HouseholdType	1 if no children, 2 if with children and old people, 3 if with children but no old people					1: 88 2: 10 3: 25
DependenceRatio (%)	The percentage of the number of children and old people in the household	0	66.67	14.46	17.37	
PctFemaleLabor (%)	The percentage of female labor of total number of labor in the household	0	100	47.70	16.25	
NumClgStudents	The number of people who are in college	0	2	0.07	0.29	
TotalArea (mu)	The total area of farmland the household manages	0.1	19.30	6.347	4.12	
PctFlat	1 if the percentage of flat farm land is (above) average (85%) 0 if it is below average					1: 88 0: 35
AvgPlotSize (mu)	The average size of all the plots	0.05	2.35	0.69	0.34	

HaveLoans	1 if the household has any loans, otherwise 0					1: 55 0: 68
SqrtOfffarmIncome (CNY)	The square-root of the amount of off-farm income	0	320.90	109.40	71.26	
HaveGovContact	1 if the household has government contact(s), otherwise 0					1: 23 0: 100
Education	1 if the highest education level of the household members is high school or above, 0 if it is below high school					1: 49 0: 74
Dependent variable at the village level (N=6)						
CloseToCity	1 if a village is close to a county capital, otherwise 0					1: 4 0:2

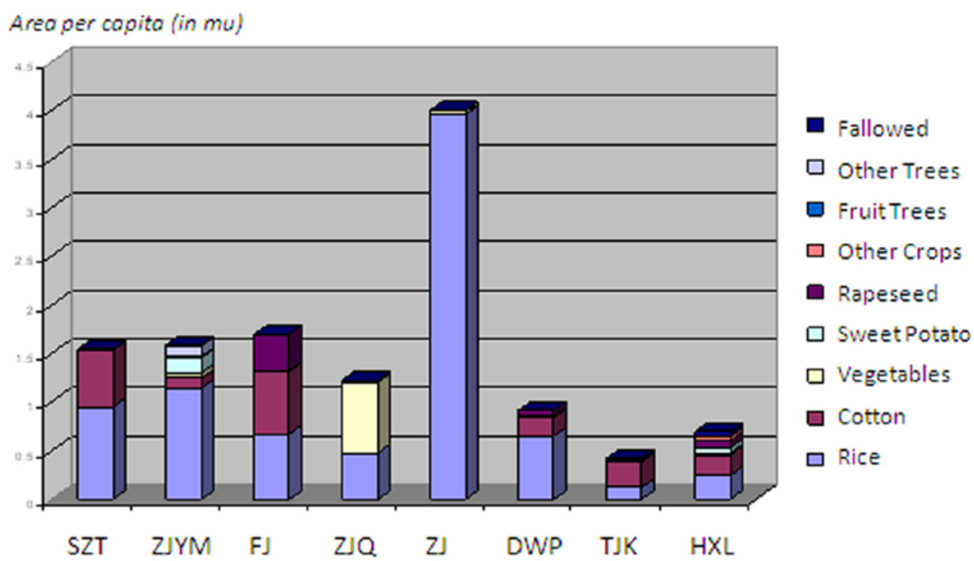


Figure 3 Major land-use types and areas in the surveyed villages.

Interviews

As a follow-up to the surveys, I re-visited all eight surveyed villages in July 2008, and conducted formal and informal interviews of 49 farmer households, 10 village leaders and 10 local government officials (5 at the county level and 5 at the town level) (Table 1).

I stayed with a household in each of three villages (ZJ, TJK and HXL), spending five to seven days in each, observing the daily life of villagers and engaging in informal conversations with them. I also interviewed some households that had not been surveyed when opportunities arose. I spent a half to full day in each of the other five villages. Initially I planned to stay in ZJQ too, a village near its county capital with a significant income from growing vegetables. But their farmland was acquired by the county government for industrial development. So, instead, I spent one day in ZJYM, which is also close to its county capital with some vegetable production. In each village, I visited the fields, if possible in the company of a farmer or village leader, to become familiarized with the quality of the natural resources.

I followed Holstein and Gubrium's (1995) approach of active interviewing. Instead of treating interviews as a one-directional flow of information from respondents to the interviewer, I worked with the respondent to construct a narrative together and interpret its meaning. For the formal interviews, I designed a set of questions with some central themes on land-use practices, land-use changes, other livelihood strategies, decision making, crop cultivation, flood risk, life attitude and living standard expectation, but was not limited by these questions. Before the interviews, I did a preliminary analysis of the survey data, and found that some factors (e.g. education and government contacts) were associated with the income of households. During the interviews, I also asked farmers their perceptions about the impacts of these factors for their livelihoods and the livelihoods of other households. When interviewing farmers, I carried on the conversations to seek in-depth understanding, and sometimes asked different questions to different farmers based on their answers and the characteristics of the households. All the interviews were digitally recorded.

To analyze interview data, I took an interpretivist's stance, interpreting the causal structure of the forces at work from individual experiences with the study subjects by studying what they do and how they think (Geertz 1973; Lincoln and Guba 1985). In practice, the methods that interpretive researchers use to interpret social facts vary greatly in the degree of formalization (Miles and Huberman 1994; Feldman 1995), from intuitive interpretation to highly formalized procedures like those based on grounded theory (Strauss and Corbin 1998). In this study, the purpose of qualitative analysis was mainly to complement and enhance the quantitative analysis, and therefore I did not adopt a highly formalized approach, but rather used qualitative information from observations and interviews to develop in-depth understandings.

Multilevel modeling

Multilevel modeling has been used to analyze land-use drivers because it explicitly accounts for variability at different levels in hierarchically structured data (Pan and Bilsborrow 2005; Overmars and Verburg 2006). Using variables from different levels without explicitly taking into account the variability between groups in a regression model leads to the potential for type I errors (Overmars and Verburg 2006).

I developed a three-level model to capture the biophysical properties of plots (level-1), the characteristics of households (level-2) and the location of a village (level-3). Models were fitted separately for one-season rice and cotton to explore what factors are associated with the choice to plant these crops. One-season rice and cotton are the dominant crops in PLR. Recently, there has been an increase of cotton production at the expense of rice. Because grain production is a concern for the Chinese government, understanding the driving forces of land-use choices of rice and cotton has policy implications. The models were generated using R software package with Laplace method.

Because land-use choice is a binary variable observed at the plot level, I used a three-level logistic model generally specified (Snijders and Bosker 1999) as:

$$\log\left(\frac{p_{ijk}}{1-p_{ijk}}\right) = \gamma_{000} + \gamma_{100}\, x_{1ijk} + \ldots + \gamma_{q00} x_{qijk} + \gamma_{010}\, z_{1jk} + \ldots + \gamma_{0r0} z_{rjk} + \gamma_{001} a_{1k} + \ldots + \gamma_{00s} a_{sk} + R_{0jk} + U_{00k} + e_{ijk} \qquad (1)$$

The model is essentially composed of two parts: the fixed effects and the random effects. In Eq. (1), $\gamma_{000} + \gamma_{100}x_{1ijk} + \ldots + \gamma_{q00}x_{qijk} + \gamma_{010}z_{1jk} + \ldots + \gamma_{0r0}z_{rjk} + \gamma_{001}a_{1k} + \ldots + \gamma_{00s}a_{sk}$ represents the fixed effects like a regular regression model, and γ_{000} is the fixed intercept. $x_{1ijk}, x_{2ijk}, \ldots, x_{qijk}$ are level-1 variables, $\gamma_{100}, \gamma_{200}, \ldots, \gamma_{q00}$ are the regression coefficients of level-1 variables, and q is the total number of level-1 variables. $z_{1jk}, z_{2jk}, \ldots, z_{rjk}$ are level-2 variables, $\gamma_{010}, \gamma_{020}, \ldots, \gamma_{0r0}$ are the regression coefficients of level-2 variables, and r is the total number of level-2 variables. $a_{1k}, a_{2k}, \ldots, a_{sk}$ are level-3 variables, $\gamma_{001}, \gamma_{002}, \ldots, \gamma_{00s}$ are the regression coefficients of level-3 variables, and s is the total number of level-3 variables. R_{0jk} represents the random effect of level-2 groups, and U_{00k} represents the random effect of level-3 groups. The random effects can be regarded as error terms at group levels and, with these random effects, the variances between groups are modeled explicitly. Such a model reveals what level-1 variables are related to the within-group variance and what group-level variables are associated with the between-group variations in intercepts (Bliese 2006). A more complex multilevel model can allow the regression coefficients of specific variables to vary between groups. In this study, I only modeled the variations of the intercept between groups.

I excluded two villages for the multilevel regression analysis because they have different land-use practices from other villages, leaving a total of 1117 plots, 123 households and six villages. While two-season rice is practiced village-wide in ZJ, the dominant land-use practice in ZJQ is vegetable cultivation. There is no cotton production in either village. I analyzed these two villages qualitatively, and incorporated their qualitative data into the overall understanding about land-use drivers. The independent variables (Table 2) were chosen based on theoretical understandings of land use in the literature, my field observations and interviews. Level-2 variables were divided into four groups: demographic variables, land resources, financial variables, and social connection and education.

A series of models with increasing numbers of variables were generated for both one-season rice and cotton. Initially, an empty model without group random effects was fitted, followed by an empty model with group random effects. Model M1 includes only level-1 variables. Four groups of level-2 variables were then added sequentially to generate M2.1, M2.2, M2.3 and M2.4. Model M3 was generated by adding the level-3 variable.

The area under the ROC curve (AUC) was calculated for each model as a measure of the goodness of fit. The ROC (receiver operating characteristic) curve describes the relationship between the proportions of true-positive and false-positive predicting from a logistic regression model based on an infinite number of probability cutoff values. AUC can be interpreted as the probability that a classifier will assign a higher score to the positive case than to the negative case, if we randomly draw pairs, one from a positive group and one from a negative group (Fawcett 2006). It can be used to compare the performances of different models (Overmars and Verburg 2005). The value of AUC ranges from 0.5 to 1.0 with 0.5 indicating no better than random prediction and 1.0 a perfect discrimination.

Results

Land-use variations across villages

The survey data and field observations revealed an obvious similarity of land use among households within villages and differences between villages. Several factors contribute to the within-village similarity and between-village differences, which suggest spatial variations in land use (Tables 1; Table 2; Figure 3).

The biophysical properties of land at a place determine what crops can grow well and which crops grow better. In each village, rice is planted in flat areas where water is available from rain or accessible more easily by irrigation, and cotton usually in higher places. In ZJ where two-season rice is cultivated village-wide, villagers plant one-season rice in low-lying areas to avoid damage from excessive water in the rainy season (April to June). In ZJYM, because its farmland is in a low-lying area and prone to rains, households only grow one-season rice. In HXL, peanuts, watermelon, sweet potatoes and many other crops are cultivated on the hilly fragmented plots because the soil of these plots, acquired through reclamation efforts, is infertile, and needs to be cultivated for many years before rice and cotton can grow.

The location of a village relative to urban centers is another important factor shaping its land use. In ZJQ and ZJYM, vegetables are cultivated and sold on the market in the country capital because they are located very close to the county capital. HXL grows many crops, mostly for self-consumption, because of its isolated location (and poor road access). The isolated location encourages a more traditional livelihood among villagers in HXL. Though the households have significant off-farm income today, most of them still grow these crops.

Government interventions have also contributed to between-village differences in land use. Cotton cultivation was promoted in some areas in PLR by the government in the 1990s. Because of this effort, cotton began to be cultivated in FJ, ZJYM, SZT, TJK and HXL. Cotton cultivation was also promoted in ZJYM, but the villagers switched back to rice because cotton did not grow well on its flood-prone low-lying farmland, which again demonstrated the important role of the natural environment. Because a similar intervention was not employed in ZJ, farmer households in ZJ do not know how to cultivate cotton. According to a local government official, ZJ and its surrounding area is a major rice production base, and the government has never introduced other crops in this area. But ZJ is also the only village where the collective irrigation system is fully functioning and well maintained, which is critical for its intensive two-season rice production. The town government manages the collective irrigation system for the entire town, and charges each household a monthly fee for it.

The irrigation system affects land use through modifying the biophysical conditions defined by the natural environment. Except for ZJ, the collective irrigation systems (built in Mao’s time) have been destroyed or are operating in a very limited capacity across the villages (Table 1). Without a well-functioning irrigation system, the harvest of rice (especially two-season rice) is much more dependent on varying weather conditions. This is part of the reason that households across the villages opt for one-season rice or cotton.

The land-use variations in space at a given time are a result of interactions among the factors related to physical environment, location, and government interventions (Figure 4). The natural environment sets the stage on which social factors play out, and it is in places where multiple crops can grow well that other factors play their roles in shaping crop choices. If we define potential crop options as all the crops that can grow on a plot, we can further divide them into two sets: feasible crop options and non-feasible crop options for the household that has its use rights. Location of the village affects the feasible set of crop options, by determining accessibility of markets, while the quality of the irrigation system affects the productivities of the crops. Government interventions in PLR have played a role in defining the feasible set of options and in shaping the conditions of the irrigation system. But cotton production was only promoted in places that were not important bases for rice production, and the collective irrigation systems in major rice-production areas are still well maintained by local governments. Major bases for rice-production are places where the farmland is suitable and highly productive for growing rice. Therefore, these government interventions have simply reinforced the important role of the natural environment.

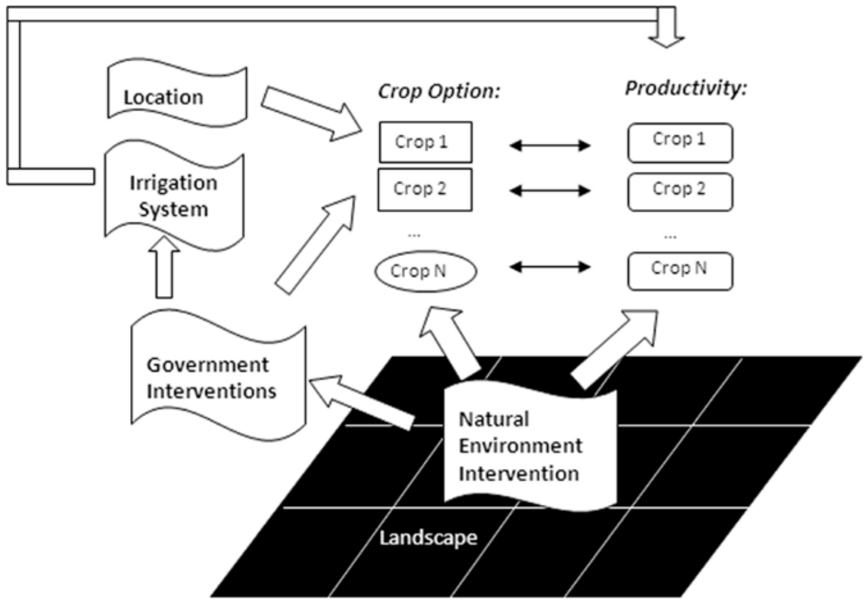


Figure 4 Interactions of the major factors in shaping spatial land-use variations.

During the central-planning era, which feasible option was chosen was largely determined by government quotas, and therefore the landscape was mainly rice paddies with few variations. Because farmers were confined to the farm by the Hukou registration system, there was also a large demand for food. Across the surveyed villages, two-season rice was widely planted.

Today, in a market economy, which feasible option is realized is more driven by market forces (as I will show in the following section), and there are more land-use variations on the landscape. As a large rural population does migratory work outside of the region, and generates a large amount of off-farm income, growing rice to meet the food demand is not as important as before. For example, many households in TJK opt to grow more cotton and buy rice for food.

Temporal changes in land use

I found several temporal trends in land use across the surveyed villages, with the most significant occurring on farmland where two-season rice used to be planted, including: two-season rice being replaced by one-season rice; an increase in cotton production in the

1990s; and, more recently, an increase in cotton production relative to rice. There was also a minor change of the decline in rapeseed production.

While increased cotton production in the 1990s was motivated by government intervention, the recent increase in cotton production is mostly a response to higher cotton prices on the market. Farmer households performed the following basic calculation, with some minor variations in yields among households. One mu (about 0.067hectares) of farmland can produce 300kg to 400kg of cotton, which sold for about 5.6CNY per kg in 2007, with a net income of at least 1000CNY after deducting costs. If used for one-season rice production, the same land area could produce about 500kg of rice, which sold for about 1.6CNY per kg in 2007, and only brought a net income of about 600CNY.

The conversion of two-season rice to one-season rice was also mostly driven by farmers' cost-benefit analysis. In most villages, total rice production in two seasons only yields about 150kg more grain on average than one season due to the failure of the collective irrigation system. But the extra cost in fertilizers, seeds, pesticides and rented machinery for harvest, along with the labor costs, counter balances the very little gain. Additionally, the prices of fertilizers and pesticides have increased significantly in recent years, further reducing the profits from rice cultivation.

Policy reforms beginning in the late 1970s were the most important driving forces for these land-use changes in PLR because they created an increasingly free-market economy, toward which farmer households have oriented their activities (Figure 5). As a result, off-farm work has become a major livelihood strategy for rural households (Table 1). Off-farm work, in general, generates higher economic return than crop cultivation. Working temporary off-farm jobs in a county capital can obtain 60CNY to 100CNY per day depending on the job type. Long-term migratory work in cities can bring an income between 10,000CNY and 30,000CNY per person in a year. Off-farm work, on one hand, reduces labor available on the farm and makes labor-intensive farming activities difficult, and on the other hand increases total income of the rural households and makes options that bring low economic returns, such as growing two-season rice and rapeseed, unattractive and abandoned.

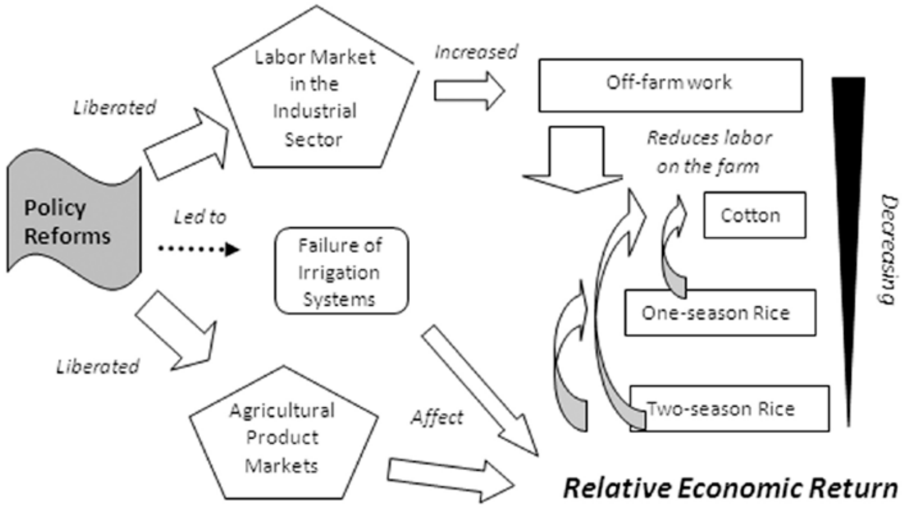


Figure 5 Policy reforms as the most important driver for temporal land-use changes.

Despite these general trends, land-use changes in PLR have not been dramatic. In fact, the current land-use practices in the surveyed villages represent only slight variations on the most traditional land-use practices in PLR. Several factors have constrained household abilities to adopt new land-use practices.

The small size of farmland holdings, allocated to farmer households through the Household Responsibility System, is a major obstacle for adopting new crop types. The Household Responsibility System initially increased agricultural output by providing incentives at the household level, but the small scale of farming is no longer suitable for a market economy. Most farmers are aware of other crop choices that would bring higher economic returns, but because their farmland plots are small and distributed in different places with different biophysical properties, it is difficult for them to grow the same crop over large areas. In addition, if only one or few households in a village adopt a new crop, it is difficult to find a stable sales channel for their new products. Merchants are not willing to come to collect them either due to the small amounts of production. Research on new land-use practices that aim to increase land profitability and reduce crop damage from flooding has been conducted by agricultural scientists in PLR (Yu 2002; Yuan, Xiao and Liu 2002; Yuan et al. 2002; Wang et al. 2002; Yuan et al. 2007). Some of these practices involve planning and using land at large scales based on zones of elevation. They are not widely accepted also because of the small farmland holdings.

Lack of technology and investment capital also constrains farmer options. For example, though some of the villagers in ZJ have considered growing cotton, they did not know how to do it. For the similar reasons, farmers across the villages have not been growing other cash crops or fruit trees, though they are aware that households in other places are successful in these practices. Their small farmland holdings further discourage them from learning new technologies. To alter land-use practices in a whole village takes an extraordinary effort and usually involves in a large amount of investment. For example, converting farmland to vegetable production requires investments in equipment and irrigation facilities.

Government agencies have been responsible for introducing and promoting new land-use practices and technologies, but such efforts are often constrained by limited human and financial resources. For example, the government has also been actively working with farmer households in creating farmer associations to encourage and help farmers to adopt new agricultural and other livelihood options (e.g. growing fruit trees and raising buffaloes). In these projects, the government often offers new technologies, provides initial investment and helps establish sales channels for farm products. Additionally, through farmer associations, households can provide credit to each other to obtain bank loans. According to some local government officials, they can only carry out these projects in a small number of places because of lacking funding and limited by human resources.

Multilevel models and the household dimension

Because the choices of cultivating one-season rice and cotton are interrelated, I interpret the results of two series of multi-level models together to understand drivers of crop choices as a whole. The differences in AUC between the null models with and without random effects for both cotton and one-season rice suggest that the variations between groups (i.e., households and villages) are large, and it is important to model the random effects of the groups explicitly.

The prediction accuracy of the one-season rice models was improved by adding plot-level variables (Table 3). This suggests that variations in the likelihood of growing rice exist between plots of a given household. A household is more likely to grow rice on larger and flatter plots and plots of average fertility. This finding is consistent with findings from the qualitative analysis that the natural environment is an important determinant for crop choice at a place. Growing rice on large plots also facilitates harvesting by machines, which is widely used. Harvesting machines are rented and usually run through the rice fields of an entire village. That adding plot-level variables has reduced the random component of variance between villages indicates that variations in the biophysical properties of farmland partially contribute to the differences between villages in the likelihood of choosing rice.

Table 3 The multi-level models for one-season rice

One-season Rice		**Variables**	**With No Variables**		**M1**	**M2.1**	**M2.2**	**M2.3**	**M2.4**	**M3**
			Without Random Effects	With Random Effects	Add Plot Variables	Add Household Structure Variables	Add Land Resource Variables	Add Financial Variables	Add Social Variables	Add Village Location
Fixed Effects										
		Intercept	-0.34***	-0.65	-0.68	-0.52	-0.43	-0.50	-0.63	-1.89**
Plot Level		PlotSize			1.81***	1.81***	1.84***	1.83***	1.82***	1.83***
		Fertility 2			0.66*	0.61*	0.59*	0.56*	0.60*	0.60*
		Fertility 3			-0.14	-0.18	-0.14	-0.15	-0.09	-0.07
		Slope 2			-2.88***	-2.92***	-3.26***	-3.27***	-3.28***	-3.26***
		Distance			-0.02@	-0.02@	-0.01	-0.01	-0.01	-0.01
House-hold Level	Household Structure	HouseholdType 2				-1.56*	-1.66*	-1.70*	-1.45*	-1.29@
		HouseholdType 3				0.34	0.34	0.33	0.19	0.16
		DependenceRatio				0.00	0.00	0.00	-0.00	-0.00
		PctFemaleLabor				-0.00	-0.00	-0.00	-0.01	-0.01
		NumClgStudents				0.13	0.06	0.06	-0.03	-0.09
	Land Resources	TotalArea					0.05	0.04	0.03	0.02
		PctFlat					-0.02*	-0.02*	-0.02*	-0.02**
		AvgPlotSize					-0.54	-0.52	-0.56	-0.63
	Financial Variables	HaveLoans 1						0.17	0.25	0.17
		SqrtOfffarmIncome						-0.00	0.00	0.00
	SocialConn &Education	HaveGovContact 1							1.02**	1.08**
		Education 1							-0.39	-0.40
Village Level		CloseToCity 1								1.85*
Random Effects	Household Level			**0.5248**	**1.4989**	**1.3702**	**1.3565**	**1.3449**	**1.1359**	**1.1267**
	Village Level			**0.9884**	**0.6587**	**0.5215**	**0.5476**	**0.6091**	**0.8910**	**0.3621**
AUC			**0.5**	**0.7813**	**0.8838**	**0.8834**	**0.8839**	**0.8841**	**0.8810**	**0.8810**

Note: Significant codes 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘@’ 0.1

The accuracy of cotton prediction on a plot was not improved substantially by adding plot-level variables (Table 4). This suggests that the variations in the likelihood of growing cotton between the plots of a given household are small, though the significance and directions of the coefficients indicate that cotton is more likely to be found on smaller plots and plots further away from the house. Cotton can grow almost anywhere except on low-lying flood-prone plots. When large plots are used to grow rice, it follows naturally that cotton is planted on smaller plots. Growing cotton on plots further away from the house is consistent with the notion that cotton is a cash crop, and rice is a subsistence crop. Overall, the impacts of biophysical properties of plots on the choice of cotton are not as important as on the choice of rice.

Table 4 The multi-level models for cotton

Cotton		Variables	With No Variables		M1	M2.1	M2.2	M2.3	M2.4	M3
			Without Random Effects	With Random Effects	Add Plot Variables	Add Household Structure Variables	Add Land Resource Variables	Add Financial Variables	Add Social Variables	Add Village Location
Fixed Effects										
		Intercept	-0.81***	-0.72@	-0.83@	-0.78	-0.74	-0.68	-0.64	-0.04
Plot Level		PlotSize			-0.60***	-0.57***	-0.64***	-0.64***	-0.65***	-0.65***
		Fertility 2			-0.02	0.01	-0.00	0.00	-0.01	0.00
		Fertility 3			0.32	0.35	0.34	0.27	0.26	0.26
		Slope 2			0.32	0.33	0.33	0.35	0.36	0.36
		Distance			0.01@	0.02*	0.02*	0.02*	0.02*	0.02*
House-hold Level	Household Structure	HouseholdType 2				-0.38	-0.45	-0.47	-0.48	-0.51
		HouseholdType 3				-0.08	0.00	0.03	0.02	0.02
		DependenceRatio				0.01	0.01	0.01	0.01	0.01
		PctFemaleLabor				0.02***	0.02***	0.02***	0.02***	0.019***
		NumClgStudents				-0.51	-0.43	-0.48	-0.44	-0.43
	Land Resources	TotalArea					0.05@	0.06*	0.06*	0.06*
		PctFlat					-0.00	0.00	0.00	0.00
		AvgPlotSize					0.00	-0.11	-0.11	-0.12
	Financial Variables	HaveLoans 1						-0.09	-0.09	-0.10
		SqrtOffarmIncome						-0.002@	-0.002@	-0.002@
	SocialConn &Education	HaveGovContact 1							0.00	-0.01
		Education 1							-0.07	-0.06
Village Level		CloseToCity 1								-0.89
Random Effects	Household Level			**0.3095**	**0.2800**	**0.0913**	**0.0396**	**0.0272**	**0.0286**	**0.0235**
	Village Level			**0.9959**	**1.0797**	**1.1188**	**1.1497**	**1.2456**	**1.2470**	**1.1089**
AUC			**0.5**	**0.8008**	**0.8023**	**0.7840**	**0.7775**	**0.7779**	**0.7786**	**0.7776**

Note: Significant codes 0 '***' 0.001 '**' 0.01 '*' 0.05 '@' 0.1

Household Type, Percentage of Flat Area and Government Contacts were significantly associated with the between-household variations in the choice of rice (Table 3). A household with children and elderly is less likely to grow rice on a given plot. In such households, usually both male and female adults do migratory work. As a result, rice consumption and labor availability are both lower in these households, and off-farm income is usually sufficient to purchase rice for food. Because rice is usually planted on flat plots and because households have limited subsistence needs for rice cultivation, a household with a greater percentage of farmland that is flat is less likely to grow rice on a given plot when controlling for the effect of the slope of plots. It is more likely to meet their rice growing needs and grow something else on additional available land. Government Contacts is positively associated with the choice of rice. Through interviews and fieldwork I found that households with government contacts are more likely to have sources of income near villages other than crop cultivation. Because they do not have much labor for crop cultivation, and rice cultivation is less labor intensive, they choose to grow more rice.

The Percentage of Female Labor and Total Area of Farmland were both significantly associated with the between-household variations in the choice of cotton on a plot (Table 4). Across the villages, I observed that most males do migratory work while some females stay at home. Women and the elderly are the major work force on the farm. The major task for the elderly is taking care of children. Because cotton cultivation generates more income than rice but is more labor intensive, those households with female labor on the farm are more likely to choose cotton over rice on a plot. That a household with larger farmland area is more likely to grow cotton on a plot is consistent again with the notion that cotton is a cash crop. Extra plots are used to grow cotton and increase income after subsistence needs are met. Off-farm Income is negatively associated with the choice of cotton, though the association is not very strong. As cash sources, cotton production and off-farm activities compete for labor, with cotton cultivation being less profitable than off-farm activities. And when people have a lot of off-farm income, they do not need to grow cotton.

Adding variables at the household level significantly reduced the random part of variance between households in cotton choices (Table 4). Specifically, Household Type accounted for the most variations between households in cotton choice, and farmland resources accounted for additional variation. Household-level variables played an important role in the decisions of households to grow cotton, though they did not improve the prediction of the choice of cotton on a plot. Demographic structure was particularly important because it often determined the amount of labor on the farm. For example, if young parents do not have elderly relatives to take care of their children, they have to stay on the farm, while many households only have elderly and children present on the farm.

Adding variables at the household level reduced some household-level random variation in rice choice (Table 3), though not as significantly as in cotton choice. Household Type and Government Contacts explained the between-household variations more than other variables. The random variation among households in rice choice remained large in the full model, suggesting that large variations between households could not be explained well by these variables. Compared to other livelihood options, one-season-rice cultivation is least profitable, but also less labor intensive and most traditional. As part of the overall livelihood strategies, rice production is a result of balancing labor, farmland resource and food demand to increase overall economic benefit. Because the situations of the households differ in these aspects, the variations between households in the choice of rice have no simple explanation.

Village location relative to urban centers was significantly associated with between-village variations in rice choice, and adding village location also largely reduced the village-level random variation (Table 3). In the villages near a county capital, households were more likely to grow rice on an individual plot. Through interviews, I found that farmers in villages near the county capital usually spent some time working on temporary off-farm jobs in the county capital. Because rice cultivation is less labor intensive, they choose to grow more rice. Village location relative to urban centers was not significantly associated with between-village variations in cotton choice (Table 4). It reduced the village-level random variation in cotton choice, but not as much as in rice choice. Through interviews, however, I found that households in HXL and TJK (both far away from the county capital) have increased their cotton production more than other villages.

The findings from the multilevel analysis are mostly consistent with the findings from qualitative analysis that crop choices on individual plots are shaped by the biophysical properties of the plots and village location. It also reveals some characteristics of households that are associated with land-use variations between households. Among them, the most important were demographic structure, government contacts (more generally interpreted as social connections) and farmland endowment.

Discussion

Household decision making and land-use patterns

Farmer households in PLR are economic agents. They are well informed about possible land-use choices and livelihood options and the costs and benefits associated with them, though they may not have the skills to implement them. Land-use decisions are part of the overall livelihood strategies of rural households. To increase total economic benefits in a market economy, a household allocates its labor to feasible off-farm and agricultural activities and farmland to different crops by giving higher priorities to activities that generate higher economic returns (Figure 6).

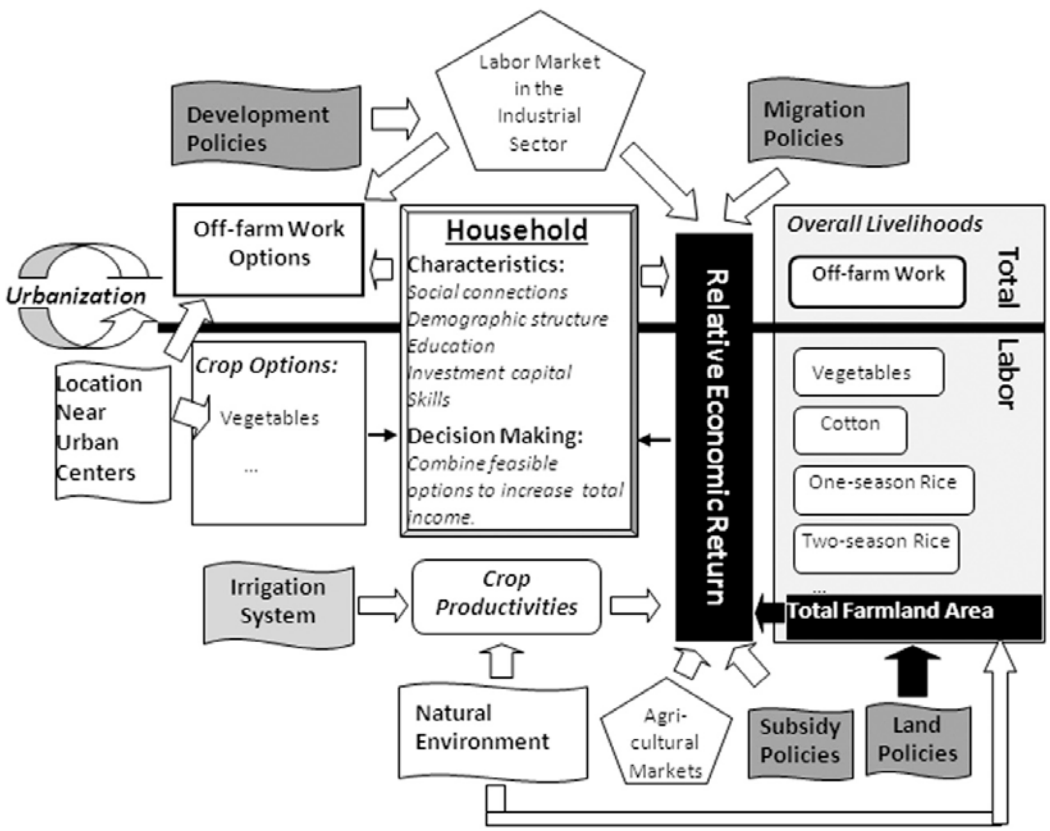


Figure 6 Land-use drivers and decision-making of the households.

The livelihoods of rural households in PLR can be viewed as comprising of off-farm work, vegetable, cotton, one-season rice and two-season rice production, with some of them being zero because they are not feasible or have too low an economic return (Figure 6). In general, vegetable production generates better economic returns than cotton and rice. With higher market prices and a year-long production cycle (three harvests a year), one mu of farmland used to bring about 6000CNY to 8000CNY income from growing vegetables in ZJQ before its farmland was acquired by the government. And this is why households in ZJQ did not grow cotton. Compared to other options, two-season rice has lower economic return, and therefore is not practiced in most places anymore. In ZJ, however, with its large farmland area and productive rice paddies supported by an irrigation system and subsidies for rice cultivation (about 100CNY per mu for two-season rice and 50CNY for one-season rice in 2007), one mu of two-season rice generated an income not much lower than cotton. Two-season rice cultivation, which is facilitated by machine harvest, is less labor intensive than cotton. Therefore, though lack of skills may have prevented farmer households in ZJ from growing cotton, the practice of two-season rice can still be explained mostly by the cost-benefit analysis.

Some factors have direct impacts on land-use choices (Figure 6). The market prices of agricultural products and production materials directly affect the relative economic returns of crops. The biophysical properties of farmland determine which crops yield more output. The functioning of the irrigation system increases the yields of crops, particularly for rice. Interacting with labor, total farmland area not only defines the farmland endowment of a household, but also affects the productivity and economic returns of farmland. In addition to preventing the adoption of new land-use practices, the current small farmland holdings of households have a negative impact on the amount of effort households put into crop cultivation. In fact, large scales of agricultural production can produce an income comparable to or even better than off-farm work. For example, if a household manages 100mu of farmland, it can make about 60,000CNY from growing one-season rice without taking account of the savings in costs and higher efficiency due to large-scale farming. Among all the factors that have a direct impact on land-use choices, farmland area has the potential to effectively change the relative economic returns of off-farm and farming options.

Because crop cultivation generates lower income than off-farm activities, in general, land-use choices are, to a large degree, affected by other livelihood options. The characteristics of a household are essential in determining its off-farm options, and therefore also important for affecting their land-use choices. Those households that have better social connections, investment capital, skills and education, have access to better livelihood options, such as doing business, purchasing and operating machines and finding salary-based jobs. When a household has better off-farm options, it usually has less labor to spend on farming activities and tends to grow more rice, if it still cultivates crops. Most households, however, only have migratory work and crop cultivation as their feasible options. They send the household members who can find it to do migratory work, with the rest growing crops on the farm. Though crop cultivation has low economic return, it is always a feasible option, and therefore practiced as long as it is still profitable. For these households, demographic structure can affect farm labor availability. Labor available on the farm and relative economic returns of the crops then determine their land-use choices.

Village location relative to urban centers has both direct and indirect impacts on land use (Figure 6). Proximity to an urban center directly affects land-use types, and households near urban centers, like ZJQ, can grow vegetables (instead of cotton) to make more money. Urban centers also offer off-farm job opportunities for household that live within the distance accessible by motorcycle and bus, which increases the proportion of rice (compared to cotton). This is why DWP has a larger area planted in rice than cotton, though its farmland is not in low-lying areas and is suitable for growing cotton too. In places far away from urban centers, households do not have off-farm work opportunities that do not require migration. To optimize economic output from limited farmland, they have to grow more cotton, as the households in HXL and TJK do. In PLR, transportation costs affect the choice of vegetable cultivation, and commercial vegetable production is usually found very near urban centers. That vegetable cultivation is no longer a feasible option at greater distances from urban centers can be explained as a consequence of increasing transportation cost[2].

Therefore, the spatial pattern of land use in PLR is, first of all, defined by the potentials laid out by the natural environment, and then shaped by location relative to urban centers and finely tuned at the micro scales by the characteristics of households. As a result, the landscape in PLR is mostly a mosaic of rice, cotton and vegetables, with one-season rice in low-lying areas and patches of other minor crops in hilly areas. In general, we are more likely to see vegetable fields near urban centers, and we expect to see more rice paddies first (mostly one-season rice with the exception of two-season rice in areas that are major bases for agricultural production), and then an increase in cotton fields at greater distances from these centers. Individual household characteristics modify this broad pattern at the micro level by affecting the proportions of cotton and rice.

In the dynamic process of urbanization, land-use changes in PLR are mostly driven by policies and market forces at the macro level (Figure 6). In the past, policy reforms have created an increasingly free-market economy, which greatly changed the livelihoods of rural households and led to the major land-use changes in PLR. Currently, the land-use choices of rural households are more driven by market forces, but policies still and will continue to play an important role in driving land-use change in PLR and rural China. Development policies in general affect job opportunities and wage levels of rural households in the industrial sector. Migration policies that specify social security and benefits of migrant workers affect the decisions of rural households on whether to settle permanently in cities and how to deal with their farmland-use rights in the countryside. In the agricultural sector, subsidies to grain production increase the economic returns of crop cultivation while land policies define the land-use rights of rural households and directly affect how rural households acquire farm land-use rights. Land policies are particularly important because they can shape farming scales in rural China, and the current small scale of farming is a barrier to further increasing agricultural productivity.

Policy implications

Understanding how farmer households make land-use and livelihood decisions, allows us to predict land-use choices by individual households in a given context. Because their land-use choices are a result of interactions between their own characteristics, the natural environment, village location and market forces within the large policy setting, they may respond to the same policy intervention differently. Therefore, to achieve a specific policy goal, policies need to be sensitive to the contexts. For example, the functioning of irrigation systems affects household land-use choices differently depending on the feasible farming and off-farm options. Improving the condition of the irrigation system is likely to increase rice production in places where households have other near-home off-farm options, but may or may not cause households in places far away from cities to switch cotton to rice.

Understanding that farmer households are economic agents and that how they respond to changes is fundamentally determined by the relative economic returns of feasible options, helps us evaluate existing policies and effectively design new policies. The elimination of agricultural taxes and the subsidization of grain production make crop cultivation marginally profitable, and therefore farmer households maintain farming operations. Their effects on promoting agricultural production, however, are small because the amount of the subsidy and tax exemption is small relative to the large income gaps between rice production and other livelihood options[3]. This supports the view of some local government officials that the money spent on subsidies for grain production would be more effective, if used to promote new land-use practices and technologies with special projects. If the government wants to promote grain production by increasing the subsidy, the amount that is needed to change the relative economic returns of different options can be calculated, and if it is too costly, alternative means need to be pursued.

In 2008, the seventeenth planning session of the Chinese Central Government Committee announced some new guidelines on rural development (Xinhua, 2008), which allow and further encourage rural households to circulate land-use rights through various forms: exchange, subcontracting, leasing and renting, transfer, and joint stock partnership. The new policy also calls for the establishment of legal markets to facilitate circulation of land-use rights. The new policy will likely succeed in promoting agricultural production and rural income because circulation of land-use rights can facilitate larger scales of farming.

A major limitation of the study comes from the limited number and geographical coverage of surveys and interviews. Because the surveyed villages are relatively close to the lake and on the west side of the lake, fruit production in the areas further away from the lake and other land-use types are not addressed[4]. Whether these conclusions can apply to the entire region around the lake is a question though some local experts believe that the insights hold beyond the surveyed areas.

Conclusions

Combining qualitative and quantitative data and methods, I examined and explained the spatial, temporal and household-level variations in land use in PLR, and demonstrated how the natural environment, location, market forces and policies interact with the characteristics of households to affect their land-use and livelihood decisions, and therefore shape spatial land-use patterns and drive land-use changes over time. I found that the spatial patterns of land-use in PLR are mostly defined by the biophysical environment, shaped by location relative to urban centers and finely tuned at the micro level by the characteristics of households. Government interventions have reinforced the role of the natural environment in shaping spatial land-use variations in PLR. Land-use changes in PLR are mostly driven in the past by policy reforms (which have created an increasingly free-market economy) and now by market forces. In the dynamic process of urbanization, policies (development policies in general and land policies in particular) will continue to play an important role in driving land-use change in rural China through shaping the dynamics of urban and rural development and by defining land-use rights of rural households.

Land-use decisions are part of the overall livelihood strategies that rural households employ to increase their economic benefits in a market economy. Because their land-use decisions may have different responses to the same intervention in different contexts, policies aimed at a particular goal need to vary across places and target the characteristics of the households. The elimination of agricultural taxes and the subsidization of grain production prevent farmer households from deserting their farmland, but their effects on increasing grain production and rural income are small. Farmland size is a lever that can be used by government interventions to promote agricultural production and rural income, and therefore the new policy that encourages circulation of land-use rights will likely succeed through facilitating larger scales of farming. Its implementation and effects remain to be seen.

Notes

1. The Spring Festival is a national holiday celebrating the lunar New Year, in which most Chinese travel to their home towns to celebrate with family.
2. Transportation costs do not appear to affect the choice between rice and cotton. Farmers do not take their cotton or rice products to the market for sale. There are groups of farmers that compete to collect rice and cotton in villages, making a profit from selling it. I found that the prices of cotton and rice were almost the same in all villages.
3. Eliminating agricultural taxes and subsidizing rice growers do have a social effect, making farmer households feel that the government cares about them. And subsidizing grain growers (together with maintaining the irrigation system) helps keep intensive rice production in the major agricultural production bases.
4. Commercial fruit production is found mostly in hilly areas where the natural conditions are favorable for growing fruit trees, and government projects that aim to promote commercial fruit production also select places based on the natural environment. In another fieldtrip to take land-use ground control points for satellite image classification in summer 2006, I traveled around the entire lake, and observed similar land-use types in other parts of PLR.

References

Allen, J. C., and D. F. Barnes. 1985. The causes of deforestation in developing countries. *Annals of the Association of American Geographers* 75(2): 163–184.

Alonso W. 1964. *Location and land use*. Cambridge, MA: Harvard University Press.

Bliese, P. 2006. *Multilevel modeling in R 2.2: A brief introduction to R, the multilevel package and the nlme package*. http://www.unt.edu/rss/class/splus/Bliese_Multilevel.pdf (last accessed 30 June 2011).

Chen, M., X. Liu, and W. Chen. 2006. Land –use change in Poyang Lake region from 1985 to 2000 and socio economic driver analysis II: Driver analysis. *Journal of An Hui Agriculture University* 33(1):123–129.

Chomitz K.M., and D.A. Gray. 1996. Roads, land use and deforestation: A spatial model applied to Belize. *World Bank Economic Review* 103:487–512.

Farmar-Bowers, Q., and R. Lane. 2009. Understanding farmers' strategic decision-making processes and the implications for biodiversity conservation policy. *Journal of Environmental Management* 90:1135–1144.

Fawcett, T. 2006. An introduction to ROC analysis. *Pattern Recognition Letters* 27:861–874.

Feldman, M. 1995. *Strategies for interpreting qualitative data*. Thousand Oaks, CA: Sage Publications.

Geertz, C. 1973. *The interpretation of cultures*. New York, NY: Basic Books.

Geist H. J., and E.F. Lambin. 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience* 52(2):143–150.

Glaser, B. G., and A. L. Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. New York: Aldine Publishing Company.

Heerink, N., F. Qu, M. Kuiper, X. Shi, and S. Tan. 2007. Policy reforms, rice production and sustainable land use in China: A macro-micro analysis. *Agricultural Systems* 94(3):784–800.

Holstein, J. A., and J. F. Gubrium. 1995. *The Active Interview*. Thousand Oaks, CA: Sage Publications.

Huang, J., and S. Dai. 2004. Agricultural structure adjustment and industrial development in the Poyang Lake Region. *Journal of Nanchang University* 28(2):134 –139.

Jiang, L., K. M. Bergen, D. G. Brown, T. Zhao, Q. Tian, and S. Qi, S. Land-cover change and vulnerability to flooding near Poyang Lake, Jiangxi Province, China. *Photogrammetric Engineering and Remote Sensing*. 74(6): 775–786.

Lambin, E. F., and H. Geist, eds. 2006. *Land-use and land-cover change: Local processes and global impacts*. Berlin: Springer.

Lambin, E. F., B. L.Turner II, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E. F. Moran, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H. Skånes, W. Steffen, G. D. Stone, U. Svedin, A. Veldkamp, C. Vogel, and J. Xu. 2001. The causes of land-use and land-cover change: Moving beyond myths. *Global Environmental Change* 11:261–269.

Lin, J. Y. 2009. *Economic Development and Transition: Thought, Strategy, and Viability.* Cambridge, UK: Cambridge University Press.

Lincoln, Y., and E. Guba. 198. *Naturalistic Inquiry*. Newbury Park, CA: Sage Publications.

Liu, T., H. Cai, J. Shao, and M. Chen. 2003. A quantitative analysis on land use structure in Poyang Lake region. *Acta Agriculturae Universitatis Jiangxiensis* 25(6):16–20.

McCracken, S. D., E. S. Brondizio, D. Nelson, E. F. Moran, A. D. Siqueira, and C. Rodriguez-Pedraza. 1999. Remote sensing and GIS at farm property level: Demography and deforestation in the Brazilian Amazon. *Photogrammetric Engineering and Remote Sensing* 65(11):1311–1320.

Miles, M., and A.M. Huberman. 1994. *Qualitative Data Analysis: A Sourcebook of New Methods* (2nd Edition). Beverly Hills, CA: Sage Publications

Nelson, G.C., and J. Geoghegan. 2002. Deforestation and land use change: Sparse data environments. *Agricultural Economics* 27:201–216.

Overmars, K. P., and P. H. Verburg. 2005. Analysis of land use drivers at the watershed and household level: Linking two paradigms at the Philippine forest fringe. *International Journal of Geographical Information Science* 19 (2):125–152.

Overmars, K. P., and P. H. Verburg. 2006. Multilevel modeling of land use from field to village level in the Philippines. *Agricultural Systems* 89:435–456.

Pan, W., and R. E. Bilsborrow. 2005. The use of a multilevel statistical model to analyze factors influencing land use: A study of the Ecuadorian Amazon. *Global and Planetary Change* 47 (2):232–252.

Perz, S. G., and R. T. Walker. 2002. Household life cycles and secondary forest cover among small farm colonists in the Amazon. *World Development* 30(6):1009–1027.

Perz, S. G. 2001. Household demographic factors as life cycle determinants of land use in the Amazon. *Population Research and Policy Review.* 20:159–186.

Rao, S, J. Fang, H. Cui, and G. Lei. 2002. Spatio-temporal changes in patterns of land use around Poyang Lake during the last decade. Resources and Environment in Yangtze Basin. 11:421-26.

Seeley, J., S. Biraro, L. A. Shafer, P. Nasirumbi, S. Foster, J. Whitworth, and H. Grosskurth. 2008. Using in-depth qualitative data to enhance our understanding of quantitative results regarding the impact of HIV and AIDS on households in rural Uganda. *Social Science & Medicine* 67:1434–1446.

Snijders, T. A. B., and R. J. Bosker. 1999. *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling.* New York: Sage Publications.

Strauss, A., and J. Corbin. 1998. *Basics of Qualitative Research, Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, CA: Sage Publications.

Swets, J. A. 1988. Measuring the accuracy of diagnostic systems. *Science* 240:1285–1293.

Turner II B. L., R. E. Kasperson, W. B. Meyer, K. M. Dow Golding, J. X. Kasperson, R. C. Mitchel, and S. J. Ratick. 1990. Two types of global environmental change: Definitional and spatial-scale issues in their human dimensions. *Global Environmental Change* 1:14–22.

Turner II B. L., R. H. Ross, and D. L. Skole, eds. 1993. Relating land use and global land-cover change: A proposal for an IGBP-HDP core project. *Report from the IGBP-HDP Working Group on Land-Use/Land-Cover Change*. Stockholm: International Geosphere-Biosphere Programme (IGBP).

Turner II, B. L., D. L. Skole, G. Sanderson, L. Fischer, L. Fresco, and R. Leemans. 1995. *Land-Use and Land-Cover Change Science/Research Plan*. Stockholm and Geneva: International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme (IGDP).

Von Thünen, J. H. 1966. Der isolierte staat in beziehung der landwirtschaft und nationalökonomie. In *Von Thünen's Isolated State,* ed. P. Hall. Oxford, UK: Pergamon Press.

Walker, R. 2004. Theorizing land-cover and land-use change: The case of tropical deforestation. *International Regional Science Review* 27(3):247–270.

Walker, R., and W. D. Solecki. 2004. Theorizing land-cover and land-use change: The case of the Florida Everglades and its degradation. *Annals of the Association of American Geographers* 94(2):311–238.

Walker, R. T., and A. K. O. Homma. 1996. Land use and land cover dynamics in the Brazilian Amazon: An overview. *Ecological Economics* 18:67–80.

Walker, R. T., S. G. Perz, M. Caldas, and L. G. Teixeira da Silva. 2002. Land use and land cover change in forest frontiers: The role of household life cycles. *International Regional Science Review* 25(2):169–199.

Wang, D., W. Chen, and Y. Ouyang. 2002. A study on techniques of growing high-yield early rice in the flood-prone Yangzi River basin. *Journal of Jiangxi Agricultural University* 24 (4):467–470.

Whitby, M. C., ed. 1992. *Land Use Change: The Causes and Consequences*. London: HMSO Books.

Wu, J., L. Zheng, and J. Chen. 2008. The land-use change in Poyang Lake region and its impacts on agricultural economics. *Economic Geography* 28(2):20–24.

Xinhua, the State News Agency. 2008. Announcement: The decisions of the Central Government of China on some important issues regarding promoting rural development reforms. *Xinhua News* 19 October.

Yu, Y. 2002. The application of several high-return production models for flood-damage-reduction agriculture in Nanchang County. *Jiangxi Agricultural Science and Technology* 3:7–8.

Yuan, Z., Y. Xiao, and G. Liu. 2002. Research on selection of flood-damage- reduction short growth early rice breeds and their adaptability. *Jiangxi Agricultural Science and Technology* 6:2–4.

Yuan, Z., Y. Xiao, G. Liu, and R. Liu. 2002. Research on flood- damage- reduction rice rotation methods and their evaluation. *Jiangxi Agricultural Science and Technology* 5:37–39.

Yuan, Z., Y. Xiao, G. Liu, and R. Liu. 2007. Research and practice on flooding risk reduction agriculture in the Poyang Lake Region. *Journal of Jiangxi Agricultural University* 19(7):112–114.

Zhao, X., and X. Guo. 2001. The analysis of sustainable development and use of agricultural land resources in the Poyang Lake region. *Economic Geography* 21(4):483 – 495.

Zhou, X. and X. Huang. 2003. A study of the impacts of government economic policies on grain and cotton production in Poyang Lake Region. *Journal of the Jiangxi Agriculture University* 25(3):442 – 445.