SPRINGER BRIEFS IN GEOGRAPHY

Qing Tian

Rural Sustainability

A Complex Systems Approach to Policy Analysis

Springer

SpringerBriefs in Geography

SpringerBriefs in Geography presents concise summaries of cutting-edge research and practical applications across the fields of physical, environmental and human geography. It publishes compact refereed monographs under the editorial supervision of an international advisory board with the aim to publish 8 to 12 weeks after acceptance. Volumes are compact, 50 to 125 pages, with a clear focus. The series covers a range of content from professional to academic such as: timely reports of state-of-the art analytical techniques, bridges between new research results, snapshots of hot and/or emerging topics, elaborated thesis, literature reviews, and in-depth case studies.

The scope of the series spans the entire field of geography, with a view to significantly advance research. The character of the series is international and multidisciplinary and will include research areas such as: GIS/cartography, remote sensing, geographical education, geospatial analysis, techniques and modeling, landscape/regional and urban planning, economic geography, housing and the built environment, and quantitative geography. Volumes in this series may analyze past, present and/or future trends, as well as their determinants and consequences. Both solicited and unsolicited manuscripts are considered for publication in this series. SpringerBriefs in Geography will be of interest to a wide range of individuals with interests in physical, environmental and human geography as well as for researchers from allied disciplines.

More information about this series at http://www.springer.com/series/10050

Qing Tian

Rural Sustainability

A Complex Systems Approach to Policy Analysis

Springer

Qing Tian
Computational Social Science Program
Department of Computational and Data Sciences
College of Science
George Mason University
Fairfax, VA, USA

ISSN 2211-4165 ISSN 2211-4173 (electronic)
SpringerBriefs in Geography
ISBN 978-3-319-52684-3 ISBN 978-3-319-52685-0 (eBook)
DOI 10.1007/978-3-319-52685-0

Library of Congress Control Number: 2017931081

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Poyang Lake is the largest freshwater lake in China. The area around Poyang Lake has such a rich tradition of rice cultivation and aquaculture that it is said to be 鱼米之乡. The Chinese 鱼translates to *fish* and 米 means *rice*; the words together mean *land of fish and rice*. But one cannot fully appreciate its meanings and the subtlety of feeling it evokes, unless one understands the significance of rice in China's development history and has seen those rice paddies, with countless streams and irrigation cannels meandering among them. It is a way of life so central and dear to generations of farmers in southern China. It is a culture, representing the wellspring of human civilization.

I did not know all these meanings growing up in northern China. But in the past ten years, I have gotten to know and grow fond of Poyang Lake and farmers in the area. It all started when I moved to Ann Arbor to pursue a PhD at the University of Michigan. I was working as a research assistant for my advisor, Dr. Daniel Brown, on a research project about land use and flood vulnerability around Poyang Lake. In the summer of 2006, we traveled around the entire lake to collect land-use data on crop and vegetation types. That was my first exposure to rural areas in southern China.

For my own dissertation research, I returned to visit nine villages around Poyang Lake in the summer of 2008. I stayed with farmer households and had the privilege of observing their daily lives. If that first visit in 2006 left me with pleasant but brief impressions on the rural south that had fascinated the mind, this field trip allowed me to learn much more about the rice culture and the rural livelihoods that had long depended on it.

Yet one didn't need to be a keen observer to see that the traditional lifestyle in鱼米之乡, which meant working and living in harmony with nature, has been changing amid development transitions. In my more recent field trips to the area in 2014 and 2015, I noticed other dramatic changes, such as the rise of "landlords" who manage large farms, and an increasingly rural and urban mix in the cities.

During my visits to the villages, I was greatly impressed by the development progress I witnessed: newly built two- or three-story houses, solar panels on the roofs, children's playgrounds and senior activity centers, concrete roads leading to every village, and in a village that had made its name for pearl growing and jewelry making, many new cars. Some of these advancements were direct outcomes of a national development initiative called “Build a New Countryside.”

What moved me most, however, were the farmers who still planted, tilled, and harvested by hand, the fishermen with tanned, weather-worn faces, and a hillside village on the lake that had developed a self-sufficient economy and maintained cultivation of many minor crops like peanut, sesame, and sweet potato, even now when it relied mainly on nonfarm income. There was a charm in them, and it was from them that I began to understand the culture of 鱼米之乡.

I was much taken with a young man who grew mushrooms in Anhui Province and wanted to farm in his own village if he could only secure a large enough farmland area; a young woman who came back to visit her parents and lamented that village girls got married too early; and a curious fisherman who came to see us while we were having dinner at the village leader’s home.

I still remember vividly a dark-faced woman who was tending both her sick husband and mother-in-law and made a living catching crayfish in the lake, and the village leader’s wife in that hillside village who always had a smile, whether she was cooking a simple winter squash dish or cutting sweet potato leaves to feed their pigs. Nor can I forget the accountant who welcomed us into his home and served our meals and refused to accept even a token payment, saying, “Let’s be friends.”

And those children in the villages—they are as lovely and intelligent as children anywhere. They give a real purpose to this work. After all, rural sustainability is all about them and their children and their children’s children. They have never left my thoughts since then.

I of course also recognized some of the rural development issues. For example, the insufficient education of children left behind by parents working far away in cities; the unoccupied new houses owned by migrant workers; and some uncultivated plots. I also learned about the pollution of rural industry, and the appropriation of farmland for industrial development, which left farmers worried about their livelihoods. Most of all, I felt the helplessness that many farmers expressed, not on account of flood hazards from Poyang Lake, but because they did not know what else, or more, they could do to improve their living conditions.

Traveling south (against the current) on the Gan River, one of the five major rivers that drain into Poyang Lake, one arrives at Nanchang, the capital of Jiangxi Province. The contrast between the villages and the city in all aspects of social, economic, and cultural development is immediately apparent.

Right on the river’s eastern bank, in the north west of the city, stands滕王阁, the Pavilion of Prince Teng. 滕王阁 is one of the three greatest pavilions in southern China. Since its construction in 653 AD, during the Tang dynasty, numerous poets have visited and enshrined the historical architecture in their famous works.

The view from the Pavilion of Prince Teng is indeed impressive. To the east, new buildings spread out wide and far in a multilayered pattern imbued with rhythms. On the other side, the river, dotted with small fishing boats, looks serene at sunset; it seems as if the whole history of Jiangxi has sunk into the river flow, and it feels heavier as the river reaches the countryside. The past and the future come together, and the city and villages are connected, right now, right here, at this vantage point.

It is a place for contemplation. How will urban culture diffuse to influence life in villages? What will the countryside look like a few decades from now? Can urban life, and the economy as a whole, prosper without healthy, strong agriculture? What kind of world will those children I met in the villages face when they grow up, and how will their lives be different from their parents'?

The work presented in this book is an attempt to make sense of what I saw and heard in the field. The reality I was exposed to was complex, and I have tried to untangle that complexity. I was fortunate because the University of Michigan's Center for the Study of Complex Systems has an array of stellar scholars, whose pioneer work significantly influenced my approach to examine rural development. And I felt an instant click with "complexity thinking."

The Poyang Lake area is a miniature of rural China. It is also a window through which to examine the larger issues of development in the developing world, where rural households struggle to improve their economic situations and are also disproportionally affected by climate variability and change. While I am clear-headed about the limitations of one case study, I cannot help wondering what the villages around Poyang Lake share with other less developed rural areas, and it is granted that at times such questions run the risk of overgeneralization.

But I do believe that government policy is essential for guiding development to facilitate rural households in their efforts to build robust livelihoods. Increasing the well-being of rural households, promoting agriculture, and reducing climate impacts are not separate goals; they should and can be addressed together. To achieve these goals, policy will have to foster healthy rural-urban development dynamics, adapt over time to suit ongoing social and environment changes, and attend to local variations as well.

Every time I visit China, I am amazed by how fast things move. I have to apologize here if any of the analyses in this book fall behind the swift steps of development. In fact, China has been constantly adjusting its development policy and is an exemplar for adaptive policymaking. Its recent plans increasingly emphasize harmonious development with local natural environments. In the field, I also saw government-supported agricultural research projects, trying different approaches in different places. In general, I feel confident about the development policy and am optimistic about the future of rural development.

Washington, DC, USA Qing Tian
October 2016

The view of Nanchang, the capital of Jiangxi Province, from the Pavilion of Prince Teng on the eastern edge of the Gan River

The view of the Gan River at sunset from the Pavilion of Prince. In the background is new development of Nanchang along the Gan River's western bank

Children in a village alongside the Gan River, where the river flows into Poyang Lake

Introduction

Rural Development in the Context of Climate Variability (and Change)

The challenges confronting rural development in less developed areas that are affected by climate impacts are many and daunting. Improving rural livelihoods in the developing world has generally been challenging (World Bank 2008; UNDP 1990–2014); extreme climatic events impose an additional constraint (Kates 2000; Adger et al. 2006; Kates and Dasgupta 2007; Takeuchi and Aginam 2011). Persistently low development contributes to low levels of human well-being and limits the capacity of rural households to cope with and adapt to climate impacts as well (Ribot et al. 1996; Adger et al. 2003; O'Brien et al. 2004; Lemos et al. 2007; Eakin et al. 2014; McCubbin et al. 2015; Agrawal and Lemos 2015; Warner et al. 2015).

Furthermore, as rural households across developing countries continue to participate in larger economies, their livelihoods are increasingly affected by new dynamics beyond their local contexts (DeFries et al. 2010; Seto et al. 2012; Liu et al. 2013a; Meyfroidt et al. 2013; Verburg et al. 2013; Seto and Reenberg 2014). Rapid urbanization, in particular, and the broad development dynamics associated with urbanization all influence the land-use and livelihood decisions of rural households, affecting their well-being and overall agricultural development (Rigg 2006; Satterthwaite et al. 2010; Rigg et al. 2012; Henley 2012; Hazell and Rahman 2014; Dercon 2013; Wilson and Burton 2015; Tian et al. 2015).

Nonfarm work is generally seen as a complement to agricultural income and is often examined from the perspective of income diversification. Remittances from nonfarm work have helped to finance innovation and intensification of farming (Tiffen 2003; Hoang et al. 2005, 2008). Participation in urban economies has contributed to a reduction in rural poverty (Deshingkar 2006; De Janvry et al. 2005; Glauben et al. 2012). Rural households near urban centers have also benefited from nonfarm opportunities and access to markets (Hoang et al. 2008; Tian et al. 2016).

However, some new empirical evidence suggests that the diversification of rural livelihoods may be short-lived because migrant workers lack professional skills, and the instability of their work is actually associated with a welfare cost for rural households (Dzanku 2015). Additionally, greater livelihood diversity may not be associated with higher levels of household well-being (Gautam and Andersen 2016). It is not diversity per se but the types of activities that are important and affect the well-being of rural households (Martin and Lorenzen 2016).

Rapid urbanization in China, for example, has profoundly transformed the livelihoods of rural households. Participation in the urban economy and the wider, overall economic growth have contributed to improved rural living standards. However, rural income has consistently lagged behind urban income, and a broader prosperity gap persists between urban and rural areas (Long et al. 2010; Liu et al. 2013a; Li et al. 2015). The average net income for rural residents was 134CNY, 2,253CNY, and 9,892CNY in 1978, 2000, and 2014, respectively, compared to 343CNY, 6,280CNY, and 29,381CNY for urban residents (NSBC 2015). The average expenditure of rural and urban households in 2014 was 8,744CNY and 25,449CNY, respectively (NSBC 2015).

Meanwhile, increasing nonfarm income is associated with the decline of agriculture, especially in those regions with relatively high industrial development, because nonfarm work in general brings higher economic returns than does crop cultivation (Liu et al. 2005; Deng et al. 2006; You et al. 2011; Jiang et al. 2013; Tian et al. 2015). Further improving rural income, reducing the rural-urban gap, and promoting agriculture have remained major challenges for the Chinese government.

This book addresses the complex social and environmental processes that shape the livelihoods of rural households, and attempts to provide scientific support for government policy to improve human development and mitigate climate impacts in less developed areas. It integrates useful ideas from the research in natural hazards and climate change into a larger framework of sustainability, and tries to operationalize the concept of sustainability, from the perspective of coupled human-environment systems (CHES).

A CHES perspective allows us to examine an array of social, economic, and environmental factors, including climate, which affect human development in a place, and to consider both local environments and broad development context (Levin 1999; Holling 2001; Folke et al. 2002; Gunderson and Holling 2002; Turner et al. 2003, 2007; Clark 2007; Liu et al. 2007; Ostrom 2009; Levin and Clark 2010; Moran 2010; Cioffi-Revilla 2016). Sustainability is essentially about human well-being over a long time horizon (Holdren 2008), but we must address human well-being and environmental well-being together because they are interdependent.

The book uses a complex adaptive systems (CAS) approach to analyze human-environment systems. In complex adaptive systems, networks of heterogeneous agents act and interact with one another and with the environment, giving rise to system-level properties or patterns (Gell-Mann 1994; Holland 1995, 1998, 2012; Kauffman 1995; Arthur et al. 1997; Axelrod and Cohen, 2000). Human agents, however, are embedded within large social, economic, institutional, and development contexts, and these can constrain individual options and decisions. An important role of policy is to improve these macro-level processes to create opportunities for individuals and facilitate better individual decision making.

On the other hand, while the actions and interactions of agents are the major forces shaping the state of a CAS, individual decisions and actions do not necessarily result in optimal system-level outcomes. The Prisoner's Dilemma and the Tragedy of Commons are cases in point. Another important role of policy could be setting up "smart" incentives to influence individual decisions and induce individual actions such that they collectively lead to desired system-level outcomes.

When we apply a CAS lens to examine CHES, we can understand that sustainability is an emergent property of human-environment systems. We can investigate the decision making of human agents, and the interactions among human agents and between the social and natural components in a CHES, to understand the micro- and macro-level processes underlying sustainability or unsustainability. Such understanding is important for improving macro-level processes to help individual agents increase their well-being and for designing "smart" policy to influence agent behavior, steering a CHES onto a sustainable path. These are the basic ideas of the sustainability framework.

The framework has been applied to the study of rural development in the Poyang Lake Region of China amid flood hazards. The case study shows that multiple analyses can be combined to acquire a deeper understanding of human-environment systems and provide useful insights for government policy to promote household well-being and sustainable rural development. It is the author's modest hope that this study may have taken one small step toward "solution-oriented research to provide realistic, context-specific pathways to a sustainable future" (DeFries et al. 2012).

References

Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in Development Studies, 3*(3), 179–195.

Adger, W. N., Paavola, J., Huq, S., & Mace, M. J. (Eds.). (2006). *Fairness in adaptation to climate change*. Cambridge: MIT Press.

Agrawal, A., & Lemos, M. C. (2015). Adaptive development. *Nature Climate Change, 5*(3), 185–187.

Arthur, W. B., Durlauf, S. N., & Lane, D. A. (Eds.). (1997). *The economy as an evolving complex system II*. Reading: Addison-Wesley.

Axelrod, R., & Cohen, M. D. (2000). *Harnessing complexity: Organizational implications of a scientific frontier*. New York: Basic Books.

Cioffi-Revilla, C. (2016). Social-ecological systems. In W. S. Bainbridge & M. C. Roco (Eds.), *Handbook of science and technology convergence*. Switzerland: Springer.

Clark, W. C. (2007). Sustainability science: A room of its own. *Proceedings of the National Academy of Sciences of the United States of America, 104*(6), 1737.

De Janvry, A., Sadoulet, E., & Zhu, N. (2005). *The role of non-farm incomes in reducing rural poverty and inequality in China*. CUDARE Working Papers, Department of Agricultural and Resource Economics, University of California, Berkeley. Retrieved from http://escholarship.org/uc/item/7ts2z766

DeFries, R. S., Ellis, E. C., Chapin, F. S., Matson, P. A., Turner, B. L., Agrawal, A., et al. (2012). Planetary opportunities: A social contract for global change science to contribute to a sustainable future. *BioScience, 62*(6), 603–606.

DeFries, R. S., Rudel, T., Uriarte, M., & Hansen, M. (2010). Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience, 3*(3), 178–181.
Deng, X., Huang, J., Rozelle, S., & Uchida, E. (2006). Cultivated land conversion and potential agricultural productivity in China. *Land Use Policy, 23*(4), 372–384.
Dercon, S. (2013). Agriculture and development: Revisiting the policy narratives. *Agricultural Economics 44*(s1), 183–187.
Deshingkar, P. (2006). *Internal migration, poverty and development in Asia*. ODI Briefing Paper 11. London: Overseas Development Institute.
Dzanku, F. M. (2015). Transient rural livelihoods and poverty in Ghana. *Journal of Rural Studies, 40*, 102–110.
Eakin, H. C., Lemos, M. C., & Nelson, D. R. (2014). Differentiating capacities as a means to sustainable climate change adaptation. *Global Environmental Change, 27*, 1–8.
Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *AMBIO: A Journal of the Human Environment, 31*(5), 437–440.
Gautam, Y., & Andersen, P. (2016). Rural livelihood diversification and household well-being: Insights from Humla, Nepal. *Journal of Rural Studies, 44*, 239–249.
Gell-Mann, M. (1994). *The Quark and the Jaguar: Adventures in the simple and the complex*. New York: Freeman.
Glauben, T., Herzfeld, T., Rozelle, S., & Wang, X. (2012). Persistent poverty in rural China: Where, why, and how to escape? *World Development, 40*(4), 784–795.
Gunderson, L. H., & Holling, C. S. (Eds.). (2002). *Panarchy: Understanding transformations in human and natural systems*. Washington, DC: Island Press.
Hazell, P., & Rahman, A. (Eds.). (2014). *New directions for smallholder agriculture*. Oxford: Oxford University Press.
Henley, D. (2012). The agrarian roots of industrial growth: Rural development in South-East Asia and sub-Saharan Africa. *Development Policy Review, 30*, 25–47.
Hoang, X., Dang, N., & Tacoli, C. (2005). *Livelihood diversification and rural–urban linkages in Vietnam's Red River Delta*. London: IIED.
Hoang, X. T., Dinh, T. T. P., & Nguyen, T. H. (2008). *Urbanization, fruit production and rural livelihood transformations in the Mekong Delta*. London: IIED.
Holdren, J. P. (2008). Presidential Address: Science and technology for sustainable well-Being. *Science, 25*, 424–434.
Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. New York: Basic Books.
Holland, J. H. (1998). *Emergence: From chaos to order*. New York: Perseus Books.
Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems, 4*(5), 390–405.
Holland, J. H. (2012). *Signals and boundaries: Building blocks for complex adaptive systems*. Cambridge: MIT Press.
Jiang, L., Deng, X., & Seto, K. C. (2013). The impact of urban expansion on agricultural land use intensity in China. *Land Use Policy, 35*, 33–39.
Kates, R. W. (2000). Cautionary tales: Adaptation and the global poor. In *Societal adaptation to climate variability and change* (pp. 5–17). Dordrecht: Springer.
Kates, R. W., & Dasgupta, P. (2007). African poverty: A grand challenge for sustainability science. *Proceedings of the National Academy of Sciences, 104*(43), 16747–16750.
Kauffman, S. (1995). *At home in the universe: The search for the laws of self-organization and complexity*. New York: Oxford University Press.
Lemos, M. C., Boyd, E., Tompkins, E. L., Osbahr, H., & Liverman, D. (2007). Developing adaptation and adapting development. *Ecology and Society, 12*(2), 26.
Levin, S. A. (1999). *Fragile dominion: Complexity and the commons*. New York: Basic Books.
Levin, S. A., & Clark, W. C. (2010). *Toward a science of sustainability* (CID working paper No. 196). Cambridge: Center for International Development, Harvard University.

Li, Y., Long, H., & Liu, Y. (2015). Spatio-temporal pattern of China's rural development: A rurality index perspective. *Journal of Rural Studies, 38*, 12–26.
Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., et al. (2007). Complexity of coupled human and natural systems. *Science, 317*(5844), 1513–1516.
Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., et al. (2013a). Framing sustainability in a telecoupled world. *Ecology and Society, 18*(2), 26.
Liu, J., Liu, M., Tian, H., Zhuang, D., Zhang, Z., Zhang, W., & Deng, X. (2005). Spatial and temporal patterns of China's cropland during 1990–2000: An analysis based on Landsat TM data. *Remote Sensing of Environment, 98*(4), 442–456.
Liu, Y., Lu, S., & Chen, Y. (2013b). Spatio-temporal change of urban–rural equalized development patterns in China and its driving factors. *Journal of Rural Studies, 32*, 320–330.
Long, H. L., Liu, Y. S., Li, X. B., & Chen, Y. F. (2010). Building new countryside in China: A geographical perspective. *Land Use Policy 27*, 457–470.
Martin, S. M., & Lorenzen, K. (2016). Livelihood diversification in rural Laos. *World Development, 83*, 231–243.
McCubbin, S., Smit, B., & Pearce, T. (2015). Where does climate fit? Vulnerability to climate change in the context of multiple stressors in Funafuti, Tuvalu. *Global Environmental Change, 30*, 43–55.
Meyfroidt, P., Lambin, E. F., Erb, K. H., & Hertel, T. W. (2013). Globalization of land use: Distant drivers of land change and geographic displacement of land use. *Current Opinion in Environmental Sustainability, 5*(5), 438–444.
Moran, E. F. (2010). *Environmental social science: Human-environment interactions and sustainability*. Hoboken: Wiley-Blackwell.
NSBC. (2015). *China statistical yearbook*. National Bureau of Statistics of China. Retrieved from http://www.stats.gov.cn/tjsj/ndsj/2015/indexch.htm
O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., et al. (2004). Mapping vulnerability to multiple stressors: Climate change and globalization in India. *Global Environmental Change, 14*(4), 303–313.
Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science, 325*(5939), 419–422.
Ribot, J. C., Najam, A., & Watson, G. (Eds.). (1996). Climate variation, vulnerability and sustainable development in the semi-arid tropics. In *Climate variability, climate change and social vulnerability in the semi-arid tropics* (pp. 13–54). Cambridge: Cambridge University Press.
Rigg, J. (2006). Land, farming, livelihoods and poverty: Rethinking the links in the rural South. *World Development, 34*(1), 180–202.
Rigg, J., Salamanca, A., & Parnwell, M. J. G. (2012). Joining the dots of agrarian change in Asia: A 25 year view from Thailand. *World Development 40*(7), 1469–1481.
Satterthwaite, D., McGranahan, G., & Tacoli, C. (2010). Urbanization and its implications for food and farming. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365*(1554), 2809–2820.
Seto, K. C., & Reenberg, A. (2014). *Rethinking global land use in an urban era*. Cambridge: MIT Press.
Seto, K. C., Reenberg, A., Boone, C. G., Fragkias, M., Haase, D., Langanke, T., et al. (2012). Urban land teleconnections and sustainability. *Proceedings of the National Academy of Sciences, 109*(20), 7687–7692.
Takeuchi, K., & Aginam, O. (2011). Sustainability challenges and opportunities in Africa. *Sustainability Science, 6*(1), 3–5.
Tian, Q., Brown, D. G., Zheng, L., Qi, S., Liu, Y., & Jiang, L. (2015). The role of cross-scale social and environmental contexts in household-level land-use decisions, Poyang Lake Region. *Annals of Association of American Geographers, 105*(6), 1240–1259.
Tian, Q., Guo, L., and Zheng, L. (2016). Urbanization and rural livelihoods: A case study from Jiangxi Province, China. Journal of Rural Studies.
Tiffen, M. (2003). Transitions in sub-Saharan Africa: Agriculture, urbanization and income growth. *World Development 31*, 1343–1366.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., et al. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences, 100*(14), 8074–8079.

Turner, B. L., Lambin, E. F., & Reenberg, A. (2007). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences, 104*(52), 20666–20671.

UNDP. (1990–2014). Human development reports. Retrieved from http://hdr.undp.org/en/global-reports

Verburg, P. H., Mertz, O., Erb, K. H., Haberl, H., & Wu, W. (2013). Land system change and food security: Towards multi-scale land system solutions. *Current Opinion in Environmental Sustainability, 5*(5), 494–502.

Warner, B. P., Kuzdas, C., Yglesias, M. G., & Childers, D. L. (2015). Limits to adaptation to interacting global change risks among smallholder rice farmers in Northwest Costa Rica. *Global Environmental Change, 30*, 101–112.

Wilson, G. A., & Burton, R. J. (2015). 'Neo-productivist' agriculture: Spatio-temporal versus structuralist perspectives. *Journal of Rural Studies, 38*, 52–64.

World Bank. (2008). *World development report 2008: Agriculture for development*. Washington, DC: The World Bank.

You, L., Spoor, M., Ulimwengu, J., & Zhang, S. (2011). Land use change and environmental stress of wheat, rice and corn production in China. *China Economic Review, 22*(4), 461–473.

Abstract

Less developed rural areas that are affected by climate impacts face great challenges for development. This book addresses the complex social and environmental processes underlying rural livelihoods, and attempts to provide scientific support for government policy to promote sustainable development in such areas. It uses a complex adaptive systems (CAS) approach to analyze coupled human-environment systems (CHES), and treats climate as one of many factors affecting human development in a CHES. Additionally, it examines rural livelihoods within local environments, as well as the broad development context of urbanization, emphasizing variations across local contexts and rural-urban connections.

The book first presents a sustainability framework for policy analysis. The framework uses two concepts to characterize and quantify sustainability of human-environment systems. Well-being describes the state of a CHES at a given time, while resilience describes how the system's state changes over time. The bulk of the book presents a case study that examines rural development in the Poyang Lake Region (PLR). The PLR is an important agricultural area in south-central China and part of the Yangtze River Basin. The region has been historically subjected to flooding from Poyang Lake, China's largest freshwater lake. As with other rural areas in China, rural livelihoods in the PLR are deeply integrated with urban economies, and rural development faces a number of difficult issues, central to which are agricultural decline associated with increasing nonfarm work and slow growth of rural income.

The case study includes three major analyses: (1) a regional assessment of human well-being, (2) an empirical analysis of rural livelihoods, and (3) an agent-based computer model used to explore future rural development. These analyses provide a meaningful view of human development in the PLR and illustrate some of the complex local- and macro-level processes that shape the livelihoods of rural households, in the dynamic process of urbanization. They generate rich insights about how government policy might effectively improve the well-being of rural households and promote sustainable development amid social, economic, and environmental changes. The final chapters of the book discuss possible implications for other less developed rural areas and the complex systems approach to policy analysis broadly.

Contents

1 Complex Adaptive Systems and a Sustainability Framework 1
1.1 The Science of Complexity and Sustainability of Human-Environment Systems 1
1.2 A Sustainability Framework for Policy Analysis 3
1.3 Potential Usefulness of the Sustainability Framework 5
1.4 Implementation of the Sustainability Framework 7
1.4.1 Assessing Well-Being 7
1.4.2 Analyzing the Complex Processes Underlying Well-Being 8
1.4.3 Exploring Future Paths of the System 9
1.5 Looking Ahead 10
References 11

2 Rural Development in the Poyang Lake Region amid Floods 15
2.1 The Dynamic Human-Environment System around Poyang Lake . . 15
2.2 Broader Development and Policy Context in China 21
References 25

3 Assessing Human Well-Being in the Poyang Lake Region 29
3.1 Mapping Flood Risk 29
3.2 Measuring Well-Being at the Township Level 31
3.3 Assessment Results 35
3.4 Implications for Future Development and Policy Interventions 39
3.5 Conclusions 41
References 41

4 Understanding the Complex Processes Underlying Well-Being of Rural Households 43
4.1 Micro- and Macro-level Processes Affecting Rural Livelihoods 43
4.2 Measuring Well-Being of Rural Households 44
4.3 Household Surveys and Interviews 45
4.4 The Use of Quantitative and Qualitative Analyses 50

4.5 Results . . . 52
4.5.1 Differences among Villages and Local Social, Environmental Factors . . . 52
4.5.2 Low-Income Households . . . 53
4.5.3 High-Income Households and Successful Livelihood Strategies . . . 54
4.5.4 Most Households and Constraints on Rural Livelihoods . . . 58
4.5.5 Sensitivity to Flooding and Inequality in Flood Impacts . . . 61
4.6 Reflections on Policy . . . 62
4.6.1 Urbanization and Rural Development . . . 62
4.6.2 Flood Impacts and Equitable, Sustainable Development . . . 66
4.7 Conclusions . . . 66
References . . . 68

5 Exploring Future Rural Development in the Poyang Lake Region . . . 71
5.1 Modeling Future Rural Development . . . 71
5.1.1 Shaping the Future: Three Different Subsidy Policies . . . 71
5.1.2 Plausible Economic and Environmental Shocks and Resilience of Rural Development . . . 72
5.2 Model Conceptualization: Entities, Interactions, and Feedbacks . . . 72
5.3 Empirical Data Used in the Model . . . 74
5.4 Model Design and Implementation . . . 76
5.4.1 Agents: Farmer Households . . . 76
5.4.2 Land Rental Market . . . 76
5.4.3 Migratory Work Efficiency Function . . . 78
5.4.4 Rice Yield Functions . . . 79
5.4.5 Major Model Parameters and Model Initialization . . . 80
5.5 Model Verification and Validation . . . 80
5.6 Effects of Subsidy Policies at Different Stages of Development . . . 83
5.6.1 Model Experiments for Exploring the Effects of Policies . . . 83
5.6.2 Future Development in Villages with Poor, Average, and Good Farmland . . . 85
5.6.3 Policy Effects in Villages with Poor, Average, and Good Farmland . . . 90
5.6.4 Differentiating Policy Interventions across Villages and Adaptive Policy . . . 92
5.7 Resilience of Rural Development . . . 95
5.7.1 Potential Effects of Severe Floods . . . 95
5.7.2 Modeling Potential Effects of Economic Shocks . . . 96
5.7.3 Rural Development under Economic Shocks . . . 97
5.7.4 Enhancing Resilience amid Social and Environmental Changes . . . 102

5.8 Robustness Analysis . . . 104
5.9 Limitations of the Model . . . 104
5.10 Conclusions . . . 105
References . . . 107

6 Sustainability of Human-Environment Systems . . . 109
6.1 Sustainable Development in the Poyang Lake Region . . . 109
6.1.1 Major Findings from the Study . . . 109
6.1.2 Implications for Future Development and Policy Recommendations . . . 111
6.2 Implications for Sustainable Development in Other Rural Areas . . . 113
6.3 From Vulnerability to Sustainability . . . 115
6.4 A General Framework for Analyzing Global Sustainability . . . 116
6.4.1 Definitions and System Properties . . . 116
6.4.2 Broad Research Questions and Approaches . . . 118
References . . . 120

7 The Complex Systems Approach to Policy Analysis . . . 123
7.1 The Sustainability Framework and Complex Systems Approach to Policy Analysis . . . 123
7.2 Agent-Based Modeling for Policy Analysis . . . 124
7.2.1 Design Useful Models and Ask Meaningful Questions . . . 124
7.2.2 Meet the Challenge of Conceptualization . . . 125
7.2.3 Strengthen a Model's Credibility . . . 132
7.2.4 Models as Projection Systems . . . 135
7.2.5 Unlock the Modeling Potential for Policy Analysis . . . 137
7.3 An Unfolding End . . . 138
References . . . 139

Acknowledgments . . . 143

About the Author . . . 145

Index . . . 147

Chapter 1
Complex Adaptive Systems and a Sustainability Framework

Abstract This chapter describes the key features of complex adaptive systems (CAS) and presents a framework for analyzing sustainability of coupled human-environment systems (CHES). The framework uses two concepts to characterize and quantify sustainability: well-being and resilience. Well-being describes the state of a CHES at a given point in time, and resilience describes the state change of the system. The framework suggests some quantitative measures for well-being in the context of climate change and variability. It also includes specific analyses that are intended to undertsand the complex processes in a CHES and to provide scientific support for policy to promote sustainable development. The chapter closes with an overview of the study of rural development in the Poyang Lake Region of China.

Keywords Complex adaptive systems • Coupled human-environment systems • Well-being • Resilience • Sustainability • Policy analysis

1.1 The Science of Complexity and Sustainability of Human-Environment Systems

Complex adaptive systems (CAS) consist of networks of heterogeneous agents that interact with one another and with the environment, giving rise to system-level patterns or properties (Gell-Mann 1994; Holland 1995, 1998, 2012; Kauffman 1995; Arthur et al. 1997; Axelrod and Cohen 2000). Markets, economies, organizations, societies, and ecosystems are all examples of complex adaptive systems.

In a complex adaptive system, the agents learn and adapt through interactions with other agents, leading to *adaptability* of the system. Because agent behaviors are linked in a co-evolutionary way, complex adaptive systems often show "perpetual novelty," and it is difficult to predict novel system-level patterns simply by knowing the properties and actions of individual agents. In other words, the behavior of the whole system cannot be obtained by summing the behaviors of the agents in a linear way; these systems thus exhibit *non-linearity*. The *adaptive interactions* of agents that possess distinctive characteristics and experiences are the keys to understand the processes and dynamics of CAS. Such adaptive interactions also lead to other general features of complex adaptive systems.

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0_1

A complex adaptive system usually has a large state space; it may exhibit *non-equilibrium* or *multiple equilibriums*, with *tipping points* that propel it into a sudden phase transition. Complex adaptive systems can have *lever points* at which a small intervention produces large changes in system-level outcomes. One example of a lever point is a vaccine, which causes important, long-term changes in an immune system. The evolution of a CAS is also *path-dependent*, i.e., dependent upon its initial conditions and previous states. As a result, a system can experience "lock-in" on an undesirable, long-term path.

Complex adaptive systems tend to *self-organize*, often without a central control; although coherent behaviors can and often do emerge from individual agent actions and interactions, the system can fall into a state of chaos. These systems often have "*fat-tailed*" behaviors, i.e., rare events—market crashes, for example, can occur more often than a normal distribution would predict. Additionally, these systems tend to have *hierarchical structures*, with components at lower levels forming the building blocks of components at higher levels. The global economy, for example, comprises many country-level economies, which are themselves complex systems made up of yet smaller systems.

In systems dynamics, an earlier paradigm of complexity science, researchers used multiple system-level variables to describe the state of a complex system and examine the interconnected changes of these variables to explain the system's behavior and dynamics (Luenberger 1979). The newer CAS paradigm advances our understanding of complex systems by looking deeper at the role of individual agents' actions and interactions on the macro dynamics.

Coupled human-environment systems (CHES) are complex adaptive systems, in which social and natural components interact with one another (Levin 1999; Gunderson and Holling 2002; Turner et al. 2003, 2007; Clark 2007; Liu et al. 2007; Ostrom 2009; Levin and Clark 2010; Moran 2010; Cioffi-Revilla 2016). In a human-environment system, many human agents, all situated within social, economic, and institutional contexts, make decisions and interact both with other agents and with the natural system (Fig. 1.1). The natural system of a CHES also has its own biophysical processes.

When we examine human-environment systems through the lens of CAS, we can understand that *sustainability* is a system-level property emerging from the actions and interactions of human agents, the biophysical processes in the natural system, and the interactions between the social and natural components. Sustainability of a CHES, moreover, can be defined as well-being, including human and environmental well-being, over a long time horizon. Sustainability is essentially about human well-being (Holdren 2008), but we must consider environmental well-being equally because human well-being cannot be sustained in the long run in a degraded natural environment.

In any CHES, multiple issues tend to affect human and environmental well-being, so that sustainability can be characterized across a number of dimensions, including natural resources, biodiversity, pollution, climate, etc. However, for a particular human-environment system, a few dimensions, or perhaps just one, are often more important than the others. We may begin our study with the most important or

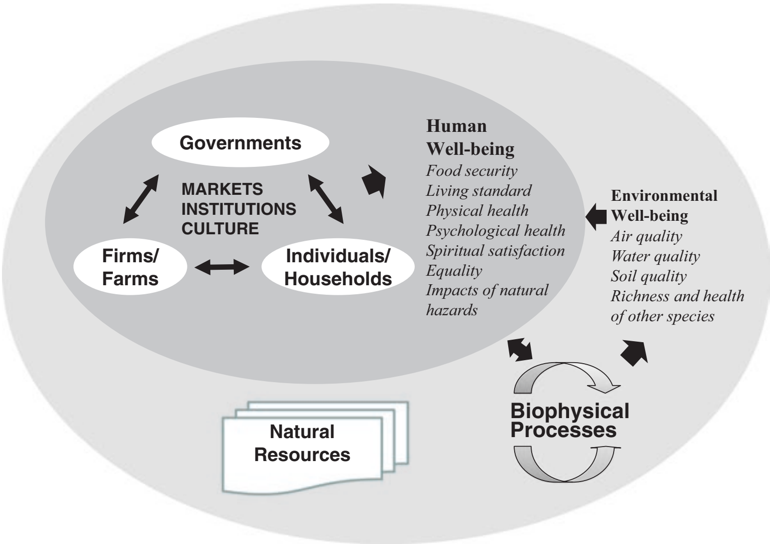


Fig. 1.1 Sustainability of coupled human-environment systems

most relevant dimensions, and later add others to increase our understanding of the system and eventually address all the issues affecting sustainability.

In the next section, I present a sustainability framework for policy analysis, in the context of climate variability (and change), for less developed areas. The framework focuses on the system's social component rather than climate dynamics because humans are the only agents in a CHES that can take deliberate actions to change the system's state. Understanding social dynamics will offer useful insights on how policy may promote positive changes in a human-environment system and direct the system toward a sustainable development path. The framework also focuses on local sustainability, i.e., the sustainability of a CHES in a specific place. I will discuss how to extend this framework to a more general analysis of global sustainability in Chap. 6.

1.2 A Sustainability Framework for Policy Analysis

The framework uses two concepts to characterize and quantify sustainability. The first, as just discussed, is *well-being*, and describes a CHES's state at a given point in time. In the context of climate variability (and change), the well-being of a CHES is defined by: (1) the human system's *exposure* to extreme climate events; (2) the human system's *development level*, which includes various aspects of human development; and (3) the *sensitivity* of human development to extreme climate events.

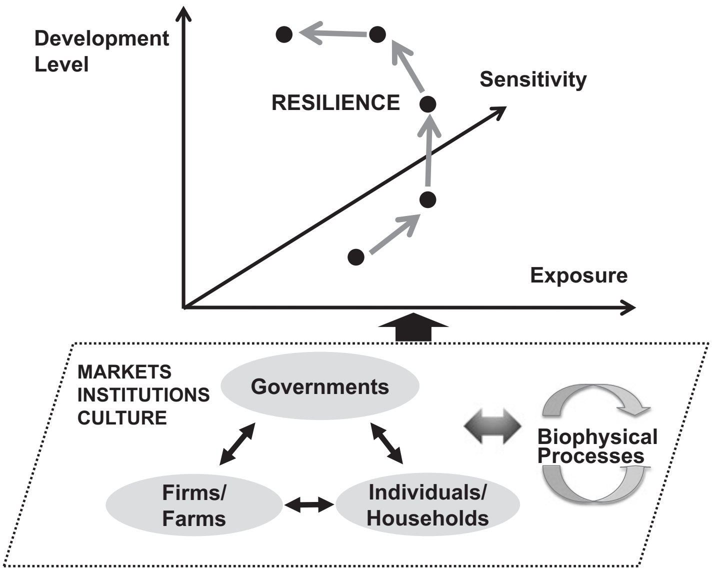


Fig. 1.2 A framework for studying sustainability in less developed areas amid climate variability (and change)

Please note the difference between exposure and sensitivity. *Exposure* characterizes the nature and degree to which the human system is exposed to extreme climate events, and is determined by the natural system. S*ensitivity* reflects the impacts of extreme climate events on human development and results from the interactions between the social and natural systems.

Also note that the definitions of exposure and sensitivity here slightly differ from the IPCC definitions. In the IPCC conceptual framework for vulnerability assessment (Houghton et al. 2001; McCarthy et al. 2001; Fussel and Klein 2006), climate extremes are treated as external to a system, and a system can be any social or natural system.

The second concept is *resilience*, which describes the state change of the system over time. A CHES is said to be resilient if it does not experience a sudden transition from one critical state of well-being to another in the face of social or environmental shocks. A CHES is defined as *sustainable* if human development has reached a certain level that ensures human well-being, and the system is resilient.

The framework is quite simple. Imagine that the state, i.e., the well-being, of a CHES at any given time is a spot in a three-dimensional space of development, exposure, and sensitivity (Fig. 1.2). Human agents in the system act and interact with one another and with the natural environment, within social, economic and institutional contexts, to shape where the spot is at a given time and how it moves in the space from time to time. *Resilience* involves tracing the trajectory of the spot over time.

Higher levels of human development coincident with lower levels of sensitivity are generally desirable. To steer a CHES toward sustainability, it is important to: (1) assess current conditions, i.e., to identify where along that well-being trajectory the system is; (2) understand the causal mechanisms, i.e., how human agents act and interact with one another and their environment to shape the system's state and drive changes in the system's state; and (3) design policies accordingly to steer the system toward more desired states. This is a continuous process of improvements and adjustments, and these three steps must be repeated over time to reflect ongoing social and environmental changes. They can be supported by employing scientific analyses that assess well-being, analyze the complex processes underlying well-being, and explore a system's future paths. I will turn to the implementations of these analyses, following a discussion on the framework's usefulness.

1.3 Potential Usefulness of the Sustainability Framework

The sustainability framework has been influenced by literature from several fields relevant to global environmental change. This section offers a brief introduction to some of the major concepts in the literature, while discussing the framework's potential usefulness. I explain why I chose some concepts over others, and how to integrate the analysis of vulnerability and adaptation into the sustainability framework to provide more useful insights for promoting human well-being in less developed areas that are affected by climate impacts.

The concepts of exposure and sensitivity are important because they reflect the nature and impacts of climate variability (and change). The research in natural hazards has long used these concepts to examine biophysical vulnerability (Burton et al. 1978, 1993). As defined in this framework, exposure and sensitivity offer objective measures of the biophysical environment and the outcome of human-environment interactions with respect to extreme climatic events. As long as the human system is exposed, and human development remains sensitive to climate impacts, people are vulnerable to harm from climate-related natural disasters. Exposure can also serve as a useful reference point to sensitivity, revealing whether human activity is exacerbating or ameliorating natural risk.

Together, measures of exposure, sensitivity, and development provide a meaningful view of human well-being in the context of climate variability (and change), and suggest where adjustments may be made (Table 1.1). Examining sensitivity along with exposure also forces decision-makers to consider specific climate risk and impacts when making development plans. This will help prevent maladaptation or an inappropriate reliance on other means, such as insurance, that may mitigate impacts locally but cause a loss of welfare at the system level.

The concept of social vulnerability, with its roots in political ecology/political economy, is essentially about human well-being. Social vulnerability is often measured by combining socioeconomic variables, such as socioeconomic status, access to resources, age and gender, the degree of urbanization, occupations, infrastructure,

Table 1.1 System states and possible implications

Development	Exposure	Sensitivity	Possible implication
High	Low	Low	Desired state
High	Low	High	Not doing right things—need to locate the sensitive part of development and make appropriate adjustments
High	High	Low	Good—doing things that mitigate natural risk
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 natural 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

education, and social capital (e.g., 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 in these contexts is human well-being. Researchers—especially those who have worked in less developed countries or with socially and economically disadvantaged groups—have recognized that it is not particularly meaningful to examine vulnerability without looking at development, and that human well-being is the real concern (Ribot et al. 1996; Kates 2000; Adger et al. 2003; Lemos et al. 2007; Wilbanks and Kates 2010; Smith et al. 2011; McCubbin et al. 2015).

The vulnerability analyses that seek to understand how social and political processes affect people’s vulnerability (Sen 1981; Hewitt 1983; Dreze and Sen 1990; Swift 1989; Watts and Bohle 1993; Blaikie et al. 1994; Ribot 2009) are important and can be expanded under the new sustainability framework to analyze the complex processes that shape the well-being of CHES. The livelihoods approach (Ellis 1998; Bebbington 1999), often used in development studies to analyze the well-being of a household, is particularly useful and can be applied to analyze the micro- and macro-level processes in CHES. The livelihoods approach can also provide insight about how the livelihoods of households can be affected by climate impacts (Eakin 2005; Paavola 2008; IPCC 2014, Rogers and Xue 2015; Lemos et al. 2016; Tian and Lemos in review).

The concept of resilience generally refers to the ability of a system to maintain its basic function and structure in the face of shocks (Holling 1973; Carpenter et al. 2001; Folke et al. 2002; Berkes et al. 2003; Folke 2006; Walker and Salt 2006). Resilience is a useful concept because it is an important property of a human-environment system and tells us how a system’s state changes. However, many human-environment systems are currently in a state of *undesirable* resilience. In these systems, human development levels are low and/or the environments suffer degradation and resource depletion. This is precisely why sustainability is an urgent issue, and why the sustainability framework in this study focuses on how to steer a system toward more desirable states.

The concept of resilience becomes more useful if we can operationalize it. There are multiple lines of resilience thinking in the literature (Walker and Salt 2006). A ball-in-a-basin model is used to illustrate a system's attractors and potential state transitions. The evolution of a system is also thought to have adaptive cycles. My intent here is not to incorporate all the meanings of resilience, but to define the term in a concrete way that is useful for the study of sustainability. Once 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 begin to define critical states. We can then combine the mathematic tools developed in systems dynamics with new modeling tools for analyzing complex adaptive systems to trace the trajectory of well-being.

When we recognize that climate is one of the factors that affect human well-being, adaptation to climate variability (and change) naturally becomes part of the sustainability agenda. Sensitivity of human development to climate impacts also provides a measure of the outcome of human adaptation: if over time people make development less sensitive to climate impacts, they are adaptive and adapting in the *right* direction.

Adaptive capacity, another central concept in the social science of climate change, is inherently dynamic and difficult to measure directly. But assessing current conditions, understanding causal mechanisms, and making adjustments accordingly are fundamental steps toward progressive adaptation. When we analyze the complex processes underlying the well-being of a human-environment system, we can gain insights into the complex processes that affect adaptive capacity as well. Therefore, these iterative steps toward sustainability are also helpful for enhancing adaptive capacity to climate variability (and change).

1.4 Implementation of the Sustainability Framework

1.4.1 Assessing Well-Being

Assessments of well-being can be carried out for a given time and at different scales. Regional assessments are particularly useful for policy-makers seeking to understand variations in exposure, sensitivity, and development levels across the region and identify problematic "hot spots." They can use the information to design policies that target different problems in different places.

Each of the three dimensions of well-being—development, exposure, and sensitivity—can be represented by multiple variables. The UN Development Programme (1990, 2007, 2008) uses life expectancy, literacy, and income to derive its human development index. These are important basic measures of human development for less developed areas.

Additional variables can be included to provide more comprehensive views of human development or to reflect specific concerns of a place. The World Bank (2009) has listed more than 800 indicators for various aspects of human development. But it is important to note here that more is not necessarily better. Including many *relevant* but *unimportant* variables is likely to mislead or overwhelm policy-makers, and prevent them from seeing the essential parts of the picture. An assessment can actually generate the most insightful information if it captures the system's key elements using the fewest variables possible.

Exposure and sensitivity measures are specific to location and type of climate event. Area extent, speed of onset, spatial distribution, temporal spacing, duration, and frequency are commonly used in natural hazard research to characterize the nature and magnitude of extreme climate events (Burton et al. 1978, 1993). These are appropriate measures for exposure to extreme climate events.

Two types of outcomes are essential to consider in measuring sensitivity: *human lives* and *economic activities*. In different places, major economic activities may differ, but in each place *land-use patterns* are direct manifestations of sensitivity. Especially for rural areas, land-use patterns indicate how climate can affect agricultural production. The distribution of important public facilities and engineering works can also affect sensitivity, and may be considered.

Exposure and sensitivity often vary spatially in a region. To characterize the spatial variations of exposure, we can define and map *risk zones*, using a theoretical approach based on the nature of the risk, or empirically based on historical data on damages suffered from extreme climate events. Land-use patterns can be interpreted from remote sensing images. Land-use maps and other GIS data, such as road networks, crucial facility locations, and population distribution, can then be combined with the risk zones to examine spatial variations of sensitivity.

1.4.2 Analyzing the Complex Processes Underlying Well-Being

Understanding how human agents in a coupled human-environment system interact with one another and with their social and natural environments to shape the well-being of the system can provide important insights into designing policies that gradually but effectively steer the system onto a path of sustainable development. Only if we understand such causal mechanisms, can we effect changes in a system.

Agent decision making is, of course, an essential part of the causal mechanisms at work in complex adaptive systems. Human agents in a CHES are, however, all embedded within large social, economic, institutional, and development contexts, which can affect and constrain individual options and decisions. Policies can play an important role in improving macro-level processes so as to create opportunities for individual agents and facilitate individual agents making better choices.

On the other hand, while individual decisions and actions are major forces driving state change in complex adaptive systems, they do not necessarily result in *optimal* system-level outcomes. The Prisoner's Dilemma and the Tragedy of the Commons are cases in point. If one is to approach policy from a CAS perspective, the goal should not be to impose central control over a system, but to set up "smart" incentives to induce individual decisions and actions that collectively lead to desired system-level outcomes.

It is therefore particularly important to examine how human agents make decisions. If we understand this, we may be able to design effective policies to improve macro-level processes and assist individual agents increase their well-being, or introduce "smart" policies to influence individual behaviors and facilitate changes toward more desired states.

To analyze the interactive processes in human-environment systems, we can combine quantitative and qualitative data and methods. Qualitative approaches, especially, allow us to develop a deeper understanding of processes and to examine social factors that are hard to quantify and therefore often omitted in quantitative analyses. Qualitative approaches, such as interviews, field observations, and participatory methods, are useful for investigating human decision making, and can help us understand how macro-level socioeconomic processes and environmental factors affect agent decisions—and, ultimately, the state of a system.

1.4.3 Exploring Future Paths of the System

Agent-based modeling (ABM) is a useful method to explore future paths of a human-environment system. Agent-based models (ABMs) simulate the decisions of heterogeneous agents in complex adaptive systems, and have been used to explain macro-level phenomena in a variety of systems, from economies and markets to social organizations and land use (Epstein and Axtell 1996; Axelrod 1997; Riolo et al. 2001; Bankes 2002; Janssen 2003; Parker et al. 2003; Gilbert 2008; Manson and Evans 2007; Miller and Page 2007; Farmer and Foley 2009; Heppenstall et al. 2012; Railsback and Grimm 2011; Cioffi-Revilla 2014; Walsh and Mena 2016).

The particular strength of agent-based modeling lies in its exploratory capabilities, and these can be tapped for policy analysis. We can use agent-based models to test the potential effects of alternative policies; if we have some idea of how a CHES might respond to a certain policy intervention, we will be more confident about its implementation. We can use ABMs to explore lever points; if we find them, we can introduce large positive changes to a system with few costs. We can use them to explore plausible scenarios of social and environmental changes; this could provide us with insight into the resilience of a CHES and whether human well-being can be sustained. We can also use agent-based models to explore the state space of a CHES; if we can identify dangerous tipping points, or conditions that lead to unsustainability, we will have a better chance to avoid a disastrous future.

1.5 Looking Ahead

The following chapters present a study of rural development, and the application of the sustainability framework, in the Poyang Lake Region (PLR) of China. The PLR is an important agricultural area in Jiangxi Province situated in the middle region of the Yangtze River Basin. Historically, the area has been subjected to flood hazards from Poyang Lake, China's largest freshwater lake. The annual per capita net income of farmers in the region was 5,789 CNY (1 USD equaled about 6.77 CNY) in 2010, below the national average of 5,919 CNY (Yan et al. 2013).

As in other rural areas in China, rural livelihoods in the Poyang Lake Region have been transitioning to an increased dependence on nonfarm work. Based on household surveys across eight villages in the region, on average 65% of rural income was derived from nonfarm sources in 2006 (Tian et al. 2015). Rural development in the PLR, and in China more generally, is facing a number of difficult issues, central to which are low rural income and agricultural decline associated with nonfarm work. In Chap. 2, I provide more details on the broader policy and development context in China, and introduce the dynamic coupled human-environment system around Poyang Lake.

Chapter 3 presents a regional assessment of human well-being carried out for 298 townships (the administrative units below counties and above villages) in the PLR. First, flood hazard zones are mapped, using an innovative geographic approach, based on a digital elevation model, levee location, height and quality, and historical data on lake levels. Measures of exposure and sensitivity at the township level are then derived, combining a land-use map interpreted from remote sensing images and a population distribution map with the flood hazard zones. Socioeconomic variables from the 2000 census are used to represent the three aspects of development in health, literacy, and income defined by UNDP.

The assessment indicates that development in the Poyang Lake Region overall is both highly exposed and sensitive to flooding risk. Sensitivity is closely related to and perhaps bound by exposure, with both levels climbing in proximity to the lake. The development level, however, is more closely associated with the degree of urbanization; higher development levels are also found in townships closer to county capitals (which are economic centers for rural Chinese counties). There are significant variations in different aspects of human well-being among the townships in the PLR. I discuss different sustainable development pathways for several types of townships and the implications for government interventions.

Chapter 4 presents an analysis of rural livelihoods, aiming to understand the complex processes that shape the well-being of rural households in the dynamic process of urbanization. The analysis is based on quantitative surveys and qualitative interviews and field observations in eight villages around Poyang Lake. It examines rural households' livelihoods against China's broad development background, and within their local contexts, which also define their exposure to flood hazards. While urbanization has had a positive effect on reducing the sensitivity of rural livelihoods to flooding, some institutional factors and macro development dynamics can affect and constrain rural households from developing viable livelihoods. I discuss how development programs and policy may simultaneously promote rural development and mitigate flood impacts.

Chapter 5 presents an agent-based model developed to explore the effects of different subsidy policies on rural development and the resilience of rural development in the PLR. The model represents land-use and livelihood decision making of farmer households in three types of villages: those with poor, average, and rich farmland. Households in the model allocate their labor between nonfarm and agricultural work, make rice cropping choices, and exchange farmland in a land rental market. The model tests three policy scenarios: subsidies to rice growers, subsidies to large farms, and subsidies to households that subcontract their farmland to other households for the long term.

The model experiments aid our understanding of the nature and potential effects of these policies across different villages at different stages of development, and how rural development may be affected by economic and environmental shocks. I discuss how policy may need to differentiate across location and adapt in the near future to promote rural development and enhance the resilience of rural development amid social and environmental changes.

Chapter 6 summarizes the findings from the PLR study and discusses the possible implications on sustainable development for other less developed rural areas. I also extend the sustainability framework into a more general framework for analyzing global sustainability.

Chapter 7 includes a reflection on the complex systems approach to policy analysis and a discussion of developing agent-based models to generate useful, convincing insights for policy analysis. The chapter concludes with a conjecture about sustainability of complex adaptive systems in general.

References

Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in Development Studies, 3*, 179–195.

Arthur, W. B., Durlauf, S. N., & Lane, D. A. (Eds.). (1997). *The economy as an evolving complex system II*. Reading: Addison-Wesley.

Axelrod, R. (1997). *The complexity of cooperation: Agent-based models of competition and collaboration*. Princeton, NJ: Princeton University Press.

Axelrod, R., & Cohen, M. D. (2000). *Harnessing complexity: Organizational implications of a scientific frontier*. New York: Basic Books.

Bankes, S. (2002). Agent-based modeling: A revolution? *Proceedings of the National Academy of Sciences of the United States of America, 99*, 7296–7303.

Bebbington, A. (1999). Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. *World Development, 27*, 2021–2044.

Berkes, F., Colding, J., & Folke, C. (Eds.). (2003). *Navigating social-ecological systems: Building resilience for complexity and change*. Cambridge: Cambridge University Press.

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (1994). *At risk: Natural hazards, people's vulnerability and disasters*. London: Routledge.

Burton, I., Kates, R. W., & White, G. E. (1978). *Environment as hazard*. New York: Oxford University Press.

Burton, I., Kates, R. W., & White, G. E. (1993). *Environment as hazard*. New York: Oxford University Press.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*, 765–781.

Cioffi-Revilla, C. (2014). Computation and social science. In *Introduction to computational social science* (pp. 23–66). London: Springer.

Cioffi-Revilla, C. (2016). Social-ecological systems. In W.S. Bainbridge, & M.C. Roco (Eds.), *Handbook of science and technology convergence*. Switzerland: Springer.

Clark, W. C. (2007). Sustainability science: A room of its own. *Proceedings of the National Academy of Sciences of the United States of America, 104*(6), 1737.

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

Dreze, J., & Sen, A. (Eds.). (1990). *The political economy of hunger* (pp. 50–67). Oxford, UK: Clarendo.

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. Retrieved from http://www.ga.gov.au.

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

Ellis, F. (1998). Household strategies and rural livelihood diversification. *Journal of Development Studies, 35*, 1–38.

Epstein, J. M., & Axtell, R. (1996). *Growing artificial societies: Social science from the bottom up*. Cambridge, MA: MIT Press.

Farmer, J. D., & Foley, D. (2009). The economy needs agent-based modelling. *Nature, 460*(7256), 685–686.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Hoiling, C. S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio: A Journal of the Human Environment, 31*(5), 437–440.

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

Fussel, H. M., & Klein, R. J. T. (2006). Climate change vulnerability assessments: An evolution of conceptual thinking. *Climatic Change, 75*, 301–32

Gell-Mann, M. (1994). *The Quark and the Jaguar: Adventures in the simple and the complex*. New York: Freeman.

Gilbert, G. N. (2008). *Agent-based models* (No. 153). Thousand Oaks: Sage.

Gunderson, L. H., & Holling, C. S. (Eds.). (2002). *Panarchy: Understanding transformations in human and natural systems*. Washington, DC: Island Press.

Heppenstall, A. J., Crooks, A. T., See, L. M., & Batty, M. (Eds.). (2012). *Agent-based models of geographical systems*. New York: Springer.

Hewitt, K. (Ed.). (1983). *Interpretations of calamity*. Boston, MA: Allen & Unwin.

Holdren, J. P. (2008). Science and technology for sustainable well-Being. *Science, 25*, 424–434.

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Cambridge, MA: Perseus Books.

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

Holland, J. H. (2012). *Signals and boundaries: Building blocks for complex adaptive systems*. Cambridge: MIT Press.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4*, 1–23.

Houghton, J. T., et al. (Eds.). (2001). *Climate change 2001: The scientific basis*. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate change 2014—Impacts, adaptation and vulnerability: Regional aspects*. Cambridge: Cambridge University Press.

Janssen, M. A. (Ed.). (2003). *Complexity and ecosystem management: The theory and practice of multi-agent systems*. New York: Edward Elgar.

Kates, R. W. (2000). Cautionary tales: Adaptation and the global poor. *Climatic Change, 45*(1), 5–17.

Kauffman, S. (1995). *At home in the universe: The search for the laws of self-organization and complexity*. New York: Oxford University Press.

Lemos, M. C., Boyd, E., Tompkins, E. L., & Osbahr, H. (2007). Developing adaptation and adapting development. *Ecology and Society, 12*(2), 375–386.

Lemos, M. C., Lo, Y. J., Nelson, D. R., Eakin, H., & Bedran-Martins, A. M. (2016). Linking development to climate adaptation: Leveraging generic and specific capacities to reduce vulnerability to drought in ne Brazil. *Global Environmental Change, 39*, 170–179.

Levin, S. A. (1999). *Fragile dominion: Complexity and the commons*. Cambridge, MA: Perseus Publishing.

Levin, S. A., & Clark, W. C. (2010). *Toward a science of sustainability* (CID Working Paper No. 196). Cambridge, MA: Center for International Development, Harvard University.

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., et al. (2007). Complexity of coupled human and natural systems. *Science, 317*(5844), 1513–1516.

Luenberger, D. G. (1979). *Introduction to dynamic systems: Theory, models, and applications*. New York: Wiley.

Manson, S. M., & Evans, T. (2007). Agent-based modeling of deforestation in southern Yucatan, Mexico, and reforestation in the Midwest United States. *Proceedings of the National Academy of Sciences, 104*(52), 20678–20683.

McCarthy, J. J., Canzianni, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (Eds.). (2001). *Climate change 2001: Impacts, adaptation and vulnerability*. Cambridge: Cambridge University Press.

McCubbin, S., Smit, B., & Pearce, T. (2015). Where does climate fit? Vulnerability to climate change in the context of multiple stressors in Funafuti, Tuvalu. *Global Environmental Change, 30*, 43–55.

Moran, E. F. (2010). *Environmental social science: Human-environment interactions and sustainability*. Hoboken, NJ: Wiley-Blackwell.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science, 325*, 419–422.

Paavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. *Environmental Science & Policy, 11*(7), 642–654.

Parker, D. C., Manson, S. M., Janssen, M. A., Hoffman, M. J., & 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*, 314–337.

Railsback, S. F., & Grimm, V. (2011). *Agent-based and individual-based modeling: A practical introduction*. Princeton, NJ: Princeton University Press.

Ribot, J. C. (2009). Vulnerability does not just fall from the sky: Toward multi-scale pro-poor climate policy. In R. Mearns & A. Norton (Eds.), *Social dimensions of climate change: Equity and vulnerability in a warming world*. Washington, DC: The World Bank.

Ribot, J. C., Najam, A., & Watson, G. (1996). Climate variation, vulnerability and sustainable development in the semi-arid tropics. In J. C. Ribot, A. R. Magalhaes, & S. S. Panagides (Eds.), *Climate variability, climate change and social vulnerability in the semi-arid tropics* (pp. 13–54). Cambridge: Cambridge University Press.

Riolo, R. L., Axelrod, R., & Cohen, M. D. (2001). Evolution of cooperation without reciprocity. *Nature, 414*, 441–443.

Rogers, S., & Xue, T. (2015). Resettlement and climate change vulnerability: Evidence from rural China. *Global Environmental Change, 35*, 62–69.

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.

Sen, A. (1981). *Poverty and famines: An essay on entitlement and deprivation*. Oxford: Oxford University Press.

Smith, J. B., Dickinson, T., Donahue, J. D. B., Burton, I., Haites, E., Klein, R. J. T., et al. (2011). Development and climate change adaptation funding: Coordination and integration. *Climate Policy, 11*(3), 987–1000.

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

The World Bank. (2009). *World development indicators*. Washington, DC: The World Bank.

Tian, Q., Brown, D. G., Zheng, L., Qi, S., Liu, Y., & Jiang, L. (2015). The role of cross-scale social and environmental contexts in household-level land-use decisions, Poyang Lake Region, China. *Annals of the Association of American Geographers, 105*(6), 1240–1259.

Turner, B., Kasperson, R., Matson, P., McCarthy, J., Corell, R., Christensen, L., et al. (2003). A Framework for Vulnerability Analysis in Sustainability Science. *Proceedings of the National Academy of Sciences of the United States of America, 100*(14), 8074–8079.

Turner, B. L., Lambin, E. F., & Reenberg, A. (2007). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences, 104*(52), 20666–20671.

UNDP. (1990, 2007, 2008). *Human development reports*. Retrieved from 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. Retrieved from http://www.tyndall.ac.uk.

Walker, B., & Salt, D. (2006). *Resilience thinking: Sustaining ecosystems and people in a changing world*. Washington, DC: Island Press.

Walsh, S. J., & Mena, C. F. (2016). Interactions of social, terrestrial, and marine sub-systems in the Galapagos Islands, Ecuador. *Proceedings of the National Academy of Sciences of the United States of America, 113*(51), 14536–14543.

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

Wilbanks, T. J., & Kates, R. W. (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.

Yan, D., Schneider, U. A., Schmid, E., Huang, H. Q., Pan, L., & Dilly, O. (2013). Interactions between land use change, regional development, and climate change in the Poyang Lake district from 1985 to 2035. *Agricultural Systems, 119*, 10–21.

Chapter 2
Rural Development in the Poyang Lake Region amid Floods

Abstract This chapter provides an introduction to the Poyang Lake Region, including local agriculture, flood history, and the levee system around Poyang Lake. The chapter also describes China's broader policy and development context, under which rural households develop their livelihoods. The PLR possesses unique social, economic, and environmental characteristics but also confronts the same issues for rural development as other rural areas in China. These issues include continued low levels of rural income and agriculture decline associated with increasing nonfarm income.

Keywords Poyang Lake Region • Agriculture • Flood hazards • Levees • Rural development issues • Policy context in China

2.1 The Dynamic Human-Environment System around Poyang Lake

The Poyang Lake Region, situated within the Yangtze River Basin, lies in northern Jiangxi Province and covers a 20,970 km^2 (Fig. 2.1). Comprising ten counties and two cities, Nanchang and Jiujiang, the PLR population totaled about 9.2 million in 2010, according to that year's census, with 78.3% of the population outside the two cities classified as rural. The region is relatively more developed than other rural areas in Jiangxi Province. The annual per capita net income of farmers was 5,789 CNY in 2010, slightly below the national average of 5,919 CNY (Yan et al. 2013). Based on household surveys across eight villages in the region, on average, 65% of rural income derived from nonfarm sources in 2006 (Tian et al. 2015a).

The PLR is a major agricultural production area for the province and, more generally, the nation. According to *Jiangxi Statistical Yearbook*, the region produced 19.08% of the total grain products in Jiangxi in 2004, as well as 32.47% of its cotton and 34.86% of its aquaculture products. The region's agriculture has been shaped by the physical environment; as a flood plain of Poyang Lake, the terrain is flat near the lake and gradually rises further away (Fig. 2.2).

Rice cultivation has traditionally dominated the economy. It is grown either once a year, from mid- or late June to early October, as "single cropping" or "one-season"

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0_2

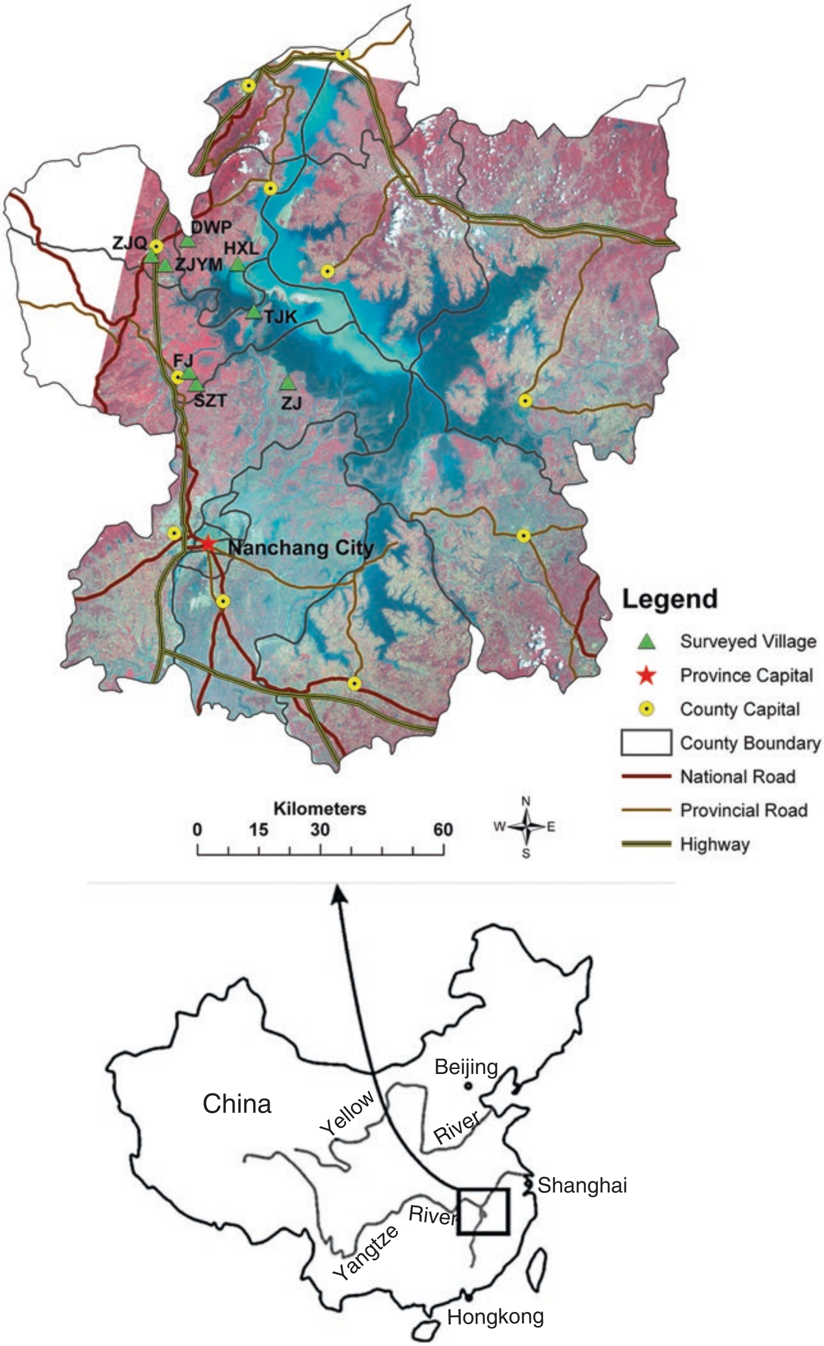


Fig. 2.1 The Poyang Lake Region (Tian et al. 2015a)

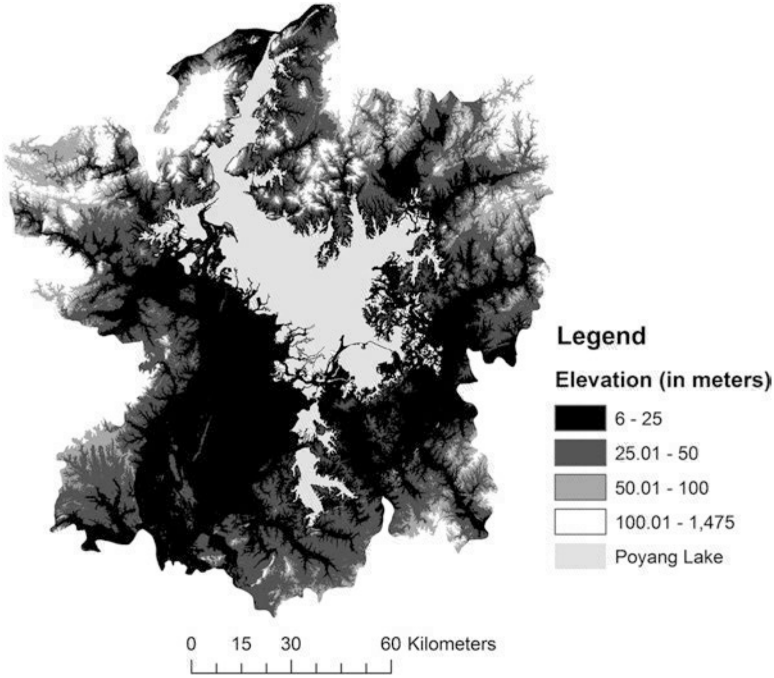


Fig. 2.2 The terrain of the PLR, mapped using a digital elevation model (Data source: Tian et al. 2015b)

rice, or double-cropped as "two-season" rice. In the latter case, the first crop is planted in late April and harvested in mid-July, and a second crop is planted in mid- or late July and harvested in late October or early November. In some areas, under the influences of nonfarm work and income, farmland plots that were traditionally used for two-season production have been converted to one-season rice (Shi et al. 2011; Tian et al. 2015a). The switch from one- to two-season rice has also been observed on remote sensing images elsewhere in the PLR (Li et al. 2012).

Cotton is an upland crop and tolerates dry conditions better than rice. It is usually planted in May and harvested from October until year's end. Other agricultural products include rapeseed, sweet potatoes, and peanuts. Rapeseed is usually planted in the rice paddies or cotton fields after the harvests, and grows throughout the winter. Figure 2.3 shows some of these farmer activities.

Poyang Lake is the largest freshwater lake in China, and human development in the PLR is vulnerable to flooding from the lake (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). Situated in a topographical depression, the lake collects water from five major rivers in Jiangxi and drains from its northern rim into the Yangtze River at Hukou, about 700 km downstream of the Three Gorges Dam. The lakebed has an average depth about 8.4 m; however, the water level varies considerably throughout the year (Xu et al. 2001; Min 1997a, b).

Fig. 2.3 Agricultural activities around Poyang Lake. *Top row*: transplanting rice seedlings; picking watermelon seeds; *Second row*: applying fertilizers to rice; growing vegetables; *Third row*: harvesting rice; cleaning boat after a fishing trip; *Bottom row*: harvesting rice with machines; working in the cotton field

From April to June, seasonal rainfalls raise the water levels of the five rivers, and the lake waters rise as well. From July to September, seasonal rains cause the water of the Yangtze River to rise, and this water can flow southward back into Poyang

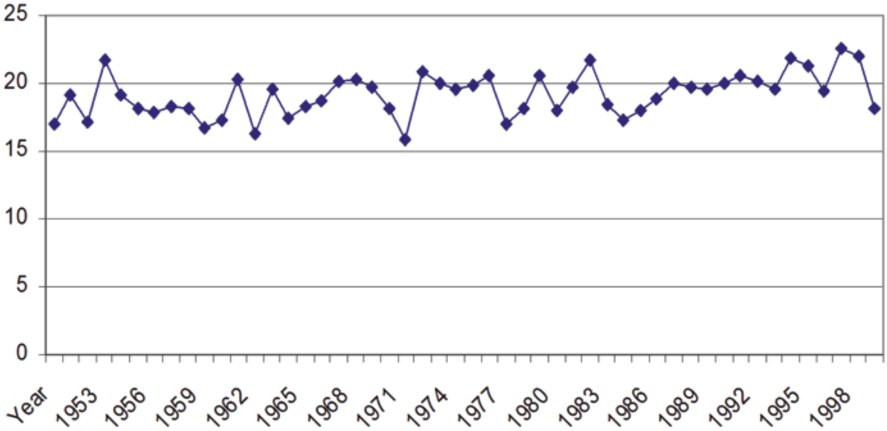


Fig. 2.4 High-water levels (in meters) from 1951 to 2001 (Data source: Tian et al. 2015b)

Lake. Historically, the most severe floods occurred when water levels in the five rivers and the Yangtze peaked at the same time. In fact, for the period 1950–1998, 83.7% of the highest lake levels were recorded from July to September, according to records at Hukou; and 65.3% of these record levels occurred in July.

Since 1950 the general trend has been toward higher rainy-season lake levels and greater frequency of severe flooding (Fig. 2.4; Min 1997a, b; Shankman and Liang 2003). During the period 1951–2001, the historical high-water level reached 22.59 m in 1998 at Hukou, and the lowest high-water level of 15.84 m occurred in 1972 (Jiang 2006; Qi et al. 2009). On average, the high-water level was 19.11 m. Nine major floods occurred in 1973, 1977, 1980, 1983, 1992, 1995, 1996, 1998, and 1999 when the high-water level exceeded 20.89 m. The 1998 food was the worst in recent history.

No severe floods have occurred since 1999; the lake responds to long-term climate and hydrologic cycles and has been in a low-level stage since 2000, according to local scientists who study its hydrology (Min and Liu, Pers. Comm.). Yet flooding concerns remain. In 2016 the lake again reached alarming levels, registering the highest water rise since 1999 and causing floods in some surrounding areas (Jiang and Qi, Pers. Comm.). Global climate change, the Three Gorges Dam, and ongoing sand dredging may increase the uncertainty of the flood regime.

For hundreds of years, the people living around Poyang Lake have built levees to protect the land from flooding. Since 1949 the Chinese government has expanded and strengthened the levee system, in part to reclaim wetlands for increased agricultural production and to accommodate the area's rapid population growth. As a result, more than 10,000 km^2 of wetland that had previously undergone annual flooding has been converted to farmland and settlements (Peng 1999). About 57% of the flood-prone area (defined as the area below an elevation of 20.75 m) in the PLR is protected by levees, and the remainder is mainly permanent and seasonal water surface (Jiang 2006).

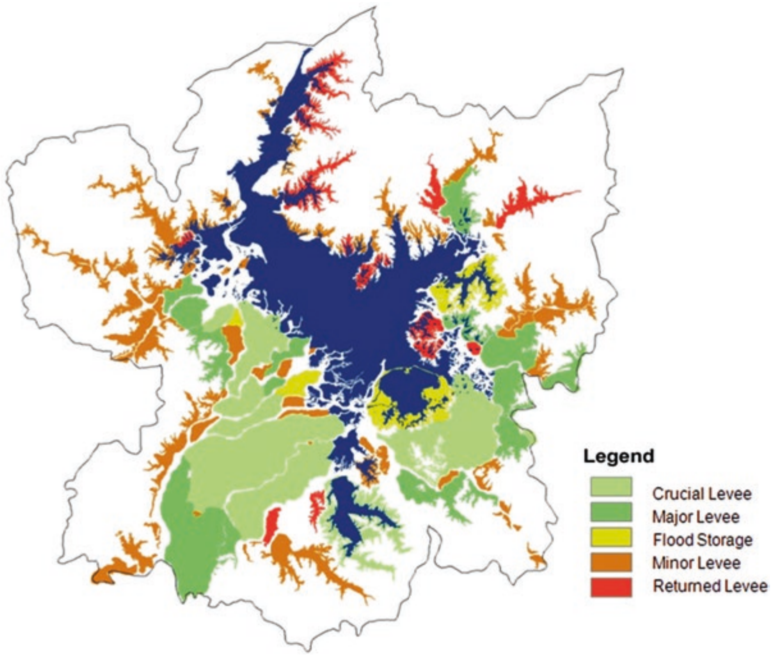


Fig. 2.5 Polders and different types of levees (Levee data source: Jiang 2006). Returned levees refer to levees that enclose abandoned polders under the "returning farmland to lake" policy

This extensive levee construction, however, offers both security and peril. It has resulted in a reduction of the lake's water storage capacity, increasing the risk of severe floods (Dou et al. 1999; Ma et al. 2004; Wu et al. 2004). The floodwaters of 1998, for example, breached many important levees and caused significant economic damage.

There are special designations for the levees, based on the amount of farmland and settlement area they contain (Peng 1999; Jiang 2006; Fig. 2.5). Crucial levees enclose more than 66.7 km^2 of farmland, as well as large cities or county capitals, and were built high and strong (i.e., with concrete). Major levees were built to protect more than 33.3 km^2 of farmland. Minor levees, usually built by rural farmers, protect farmland totaling less than 33.3 km^2 and tend to be poorly constructed and maintained. About 63% of farmland in the PLR below an elevation of 21 m was protected by crucial and major levees (Jiang et al. 2008).

In 1986 the government of Jiangxi designated four polders (the areas of land enclosed by levees) for floodwater storage, to increase the area's floodwater storage capacity. According to the policy, the levees enclosing these polders would be opened to discharge water when lake levels at Hukou reach 18.7 m. However, these polders were intensively farmed, and the government did not order the levees to be opened during the 1998 flood.

After the 1998 flood, the Chinese government implemented a policy to mitigate flooding by restoring some of the natural wetlands. This "returning farmland to lake" policy resulted in the abandonment of many minor polders. The abandoned polders were classified into two types: "partial return" and "complete return." In the partial-return polders, the villagers were resettled to higher ground, but their farmland could still be cultivated. In the complete-return polders, villagers were resettled and their farms were restored to wetland. Government regulations stipulate that when the lake levels reach 18.7 m, levees protecting partial-return polders of less than 6.67 km^2 will be opened, and when lake levels reach 19.8 m, the levees enclosing the partial-return areas of more than 6.67 km^2 will be opened.

Agricultural scientists in the Poyang Lake Region have developed land-use practices that can potentially reduce flood damage and increase land profitability (Yu 2002; Yuan et al. 2002a, b, 2007; Wang et al. 2002). These include planting new rice breeds whose growth cycles or rotation patterns will not coincide with severe flooding seasons. Some involve planning land uses based on spatial variations in elevation and other properties of the natural environment. For example, famers could cultivate flood-tolerable crops in the lower-lying areas.

These practices have not been widely adopted, in part because government agencies have limited human and financial resources for promoting them. Moreover, land-use planning based on spatial configurations usually requires consideration of a relatively large area, and such practices are not practical for individual households with small, fragmented landholdings, which is the case in many villages in the PLR. Based on the survey data collected from 1522 farmland plots in the region, on average, a household manages a farmland area of 8.28 mu (about 0.6 ha) consisting of 6.56 plots, with the mean plot size about 0.77 mu, or 0.06 ha (Tian et al. 2015a).

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

2.2 Broader Development and Policy Context in China

As with other rural areas in China, rural livelihoods in the Poyang Lake Region are affected by a variety of institutional factors and policy changes. From 1949 to the late 1970s, development policy in China focused on heavy industry under strong central planning (Lin 2009). To increase agricultural productivity and ultimately to support industrial development, communal farming systems were put into operation from 1966 to 1978. Heavy industry had no need for a large labor force, and rural migration into urban areas was controlled by a household registration system called *hukou*, which differentiated urban and rural households, and classified a household as either urban or rural. Urban *hukou* was also associated with state-subsidized social benefits at that time. For example, the work units in cities provided free housing for their "formal" employees who held urban *hukou*. The health care and education systems in cities were also limited to urban *hukou* holders. A gap in development and living standards began to grow between rural and urban areas.

As China launched economic reforms in the late 1970s, the communal systems were dismantled and replaced by a Household Responsibility System. Under the Household Responsibility System, farmland was contracted out to farmer households (for up to 30 years), shifting production decisions to individual households (Heerink et al. 2007; Long 2014). Prices for agricultural products were also increased to encourage agricultural production, and a portion of the production that exceeded a quota was sold at higher, but controlled, prices. As a result, rural income and agricultural production increased rapidly during this early period of economic reforms (Fan 1991; Lin 1992).

The period from 1985 to 1993 saw a decrease in the state control on the marketing and purchasing of 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 reintroduction 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 even 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 made provincial and local governments responsible for agricultural production to ensure food self-sufficiency at the provincial level.

The growth of the industrial sector, resulting from economic reforms, also created a demand for labor in urban centers and spurred rural-urban migration. Rural income, however, entered a stagnant period in the late 1980s, and the rate of grain production slowed as well (Huang et al. 2010). Arthur Lewis's theory of Unlimited Supply of Labor can explain, to some degree, the slow wage growth for migrant workers (Cai 2010; Yao and Zhang 2010; Zhang et al. 2011). Using a simple two-sector macroeconomic model, Lewis (1954) showed that in the initial stage of development, the industrial sector only draws additional labor from the agricultural sector, and migrant workers' wages do not rise with the growth of the industrial sector. China has a large rural labor surplus due to limited farmland (Hui and Huo 2007). The average cultivated land was about 0.6 ha per household, according to the country's 2007 agricultural census.

As a large rural population turns to migratory work, farmland is cultivated carelessly or left fallow in some areas. As noted, migrant workers were also not treated the same as "formal employees" by the work units in cities and did not enjoy the same benefits as urban *hukou* holders (Yin 2008). Disparities widened meanwhile in the broader social and cultural development between urban and rural areas. These problems were formalized into what became known as the Three Rural Issues, namely agriculture, farmers, and rural areas (Zhang et al. 2004; Zhang and Chen 2005; Shi et al. 2006; Yu and Jensen 2010). Improving rural income, reducing the rural-urban gap and promoting agriculture have remained major challenges and top priorities of the government, as described in a series of No. 1 Policy Documents issued by the Central Committee since 2004.

Also in 2004, the government initiated policies designed to improve agricultural productivity and raise farm income. These included the elimination of agriculture taxes, and subsidies to farmer households in the form of cash, high-quality seeds, and machinery. China's agricultural subsidies have risen significantly since 2008 (Gale 2013), but they have had only limited impacts toward increasing agricultural output, chiefly because nonfarm income is playing a greater role in the farmers' agricultural production decisions (Gale et al. 2005; Heerink et al. 2006; Huang et al. 2011; Gale 2013; Tian et al. 2016).

In 2006, China launched another rural development program called "building a new countryside." The program represents an integrated approach to rural development issues with multiple purposes of improving livelihoods, promoting a civilized social atmosphere, developing clean and tidy villages, and enhancing efficient management (Long and Woods 2011). The program has brought greater public investment in infrastructure across rural China. Fig. 2.6 shows a model village of the "building a new countryside" program.

The government's recent approach to promoting rural development reflects its commitment to strengthening farmer households' land rights through the issuance of land certificates and extensions of their contract periods. Land in rural China is owned nominally by "collectives," which are not well defined (Liu et al. 2014); all land in China is ultimately owned by the state. Farmer households have use rights for the contracted farmland and can subcontract their farmland to other households in private land rental markets.

The government has also been encouraging farmer households to use the land rental markets for farmland consolidation. As noted, farm operations are typically small; farmland consolidation could increase land-use efficiency and agricultural income. In the past few years, China has stepped up its effort in farmland consolidation by providing a variety of supports, ranging from cash subsidies to assistance in the construction of facilities, such as sheds, barns, and grain-sunning ground, to large farms.

Most recently, China announced new guidelines on migration and further reform of the *hukou* system in 2014. These include completely opening up towns and county-level cities to allow rural households to settle in these smaller cities; gradually opening up medium-sized cities with populations between 500,000 and one million; controlling residency in large cities with populations between one million and three million; strictly controlling populations in large cities with populations of more than five million (http://cpc.people.com.cn/n/2014/0730/c64387-25370735.html).

Fig. 2.6 A model village of the "building a new countryside" program. From top to bottom: development plans; the village; new houses; children's playground; a bulletin on which are written ten ways to become rich and ten things to avoid. Ways to become rich: learn new skills, work hard, plan carefully, obey the law, value honesty, cooperate, help one other, educate the next generation, serve the community, and love your country. Things to avoid: attending livelihoods carelessly, laziness, squandering money, gambling and using drugs…

The new policy moves away from the *hukou* system toward residency registration systems in cities. Any person can become a resident of a city if he/she obtains sufficient points that are awarded based on age, education, expertise, and other criteria. Cities will provide service and social benefits to all their residents. The point systems and the number of points required for residency differ among cities. Following these guidelines, in 2016, many major cities announced the elimination of *hukou*. Beijing, a little behind others, just announced to eliminate *hukou* on September 8, 2016 (http://zhengce.beijing.gov.cn/library/192/399/276/334/929377/80771/index.html). Jiangxi Province is expected to announce its *hukou* reform policy along this line, too.

References

Bird Life International. (2000). *Threatened birds of the world*. Cambridge, UK: Bird Life International.

Cai, F. (2010). Demographic transition, demographic dividend, and Lewis turning point in China. *China Economic Journal, 3*(2), 107–119.

Chen, W., & Zhao, X. (Eds.). (2007). *Land-use patterns and construction of security patterns in the Poyang Lake Region, China*. Beijing, China: China Agriculture Press (in Chinese).

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

Fan, S. (1991). Effects of technological change and institutional reform on production growth in Chinese agriculture. *American Journal of Agricultural Economics, 73*, 266–275.

Gale, H. F. (2013). *Growth and evolution in China's agricultural support policies* (USDA-ERS Economic Research Report, 153). Washington, DC: US Department of Agriculture, Economic Research Service. Retrieved from http://www.ers.usda.gov/media/1156829/err153.pdf

Gale, H. F., Lohmar, B., & Tuan, F. C. (2005). *China's new farm subsidies* (USDA-ERS WRS-05-01).

Heerink, N., Kuiper, M., & Shi, X. (2006). China's new rural income support policy: Impacts on grain production and rural income inequality. *China & World Economy, 14*(6), 58–69.

Heerink, N., Qu, F., Kuiper, M., Shi, X., & 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., & 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., & 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).

Huang, J., Yang, J., & Rozelle, S. (2010). China's agriculture: Drivers of change and implications for China and the rest of world. *Agricultural Economics, 41*, 47–55.

Huang, J., Wang, X., Zhi, H., Huang, Z., & Rozelle, S. (2011). Subsidies and distortions in China's agriculture: Evidence from producer-level data. *Australian Journal of Agricultural and Resource Economics, 55*, 53–71.

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

Jiang, L. (2006). *Flood risk and land use change in the wetland restoration area around Poyang Lake, China*. Ph.D. 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., & 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., & Higuchi, H. (2002). Migration routes and important resting areas of Siberian Cranes. *Biological Conservation, 106*, 339–346.

Lewis, W. A. (1954). Economic development with unlimited supplies of labour. *The Manchester School, 22*(2), 139–191.

Li, P., Feng, Z., Jiang, L., Liu, Y., & Xiao, X. (2012). Changes in rice cropping systems in the Poyang Lake Region, China during 2004–2010. *Journal of Geographical Sciences, 22*(4), 653–668.

Lin, J. Y. (1992). Rural reforms and agricultural growth in China. *The American Economic Review, 82*, 34–51.

Lin, J. Y. (2009). *Economic development and transition: Thought, strategy, and viability*. Cambridge, UK: Cambridge University Press.

Liu, Y. S., Fang, F., & Li, Y. H. (2014). Key issues of land use in China and implications for policy making. *Land Use Policy, 40*, 6–12.

Long, H. (2014). Land use policy in China: Introduction. *Land Use Policy, 40*, 1–5.

Long, H. L., & Woods, M. (2011). Rural restructuring under globalization in eastern coastal China: What can be learned from Wales? *Journal of Rural and Community Development, 6*(1), 70–94.

Ma, D. (2007). *Analysis of socio-economical vulnerability to flood in the Poyang Lake Region*. Ph.D. dissertation, Institute of Geography and Natural Resources, Chinese Academy of Sciences, Beijing, China (in Chinese).

Ma, Y., Li, J., & 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).

Qi, S., Brown, D. G., Tian, Q., Jiang, L., Zhao, T., & Bergen, K. M. (2009). Inundation extent and flood frequency mapping using LANDSAT imagery and digital elevation models. *GIScience and Remote Sensing, 46*(1), 101–127.

Shankman, D., & Liang, Q. (2003). Landscape changes and increasing flood frequency in China's Poyang Lake Region. *The Professional Geographer, 55*(4), 434–445.

Shi, X., Heerink, N., & Qu, F. (2011). Does off-farm employment contribute to agriculture-based environmental pollution? New insights from a village-level analysis in Jiangxi Province, China. *China Economic Review, 22*(4), 524–533.

Shi, Q., Pan, X., Du, T., & Wong, Z. (2006). *Jiangxi agriculture development strategies*. Beijing, China: China Agriculture Publishing House (in Chinese).

Tian, Q., Brown, D. G., Zheng, L., Qi, S., Liu, Y., & Jiang, L. (2015a). The role of cross-scale social and environmental contexts in household-level land-use decisions, Poyang Lake Region, China. *Annals of the Association of American Geographers, 105*(6), 1240–1259.

Tian, Q., Brown, D. G., Bao, S., & Qi, S. (2015b). Assessing and mapping human well-being for sustainable development amid flood hazards: Poyang Lake Region of China. *Applied Geography, 63*, 66–76.

Tian, Q., Guo, L., & Zheng, L. (2016). Urbanization and rural livelihoods: A case study from Jiangxi province, China. *Journal of Rural Studies, 47*, 577–587.

Wang, D., Chen, W., & 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., & Wu, G. (Eds.). (2006). *The program of mountain-river-lake*. Beijing, China: Science Press (in Chinese).

Wu, D., Li, R., & 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., & Zhang, J. (2001). Analysis of hydrologic characteristics of Poyang Lake. *Yangtze River, 32*, 21–27.

Yan, D., Schneider, U. A., Schmid, E., Huang, H. Q., Pan, L., & Dilly, O. (2013). Interactions between land use change, regional development, and climate change in the Poyang Lake district from 1985 to 2035. *Agricultural Systems, 119*, 10–21.

Yao, Y., & Zhang, K. (2010). Has China passed the Lewis turning point? A structural estimation based on provincial data. *China Economic Journal, 3*(2), 155–162.

Yin, P. (2008). *Study of China rural poverty under social exclusion*. Beijing, China: Knowledge Rights Publishing House (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).

Yu, W., & Jensen, H. G. (2010). China's agricultural policy transition: Impacts of recent reforms and future scenarios. *Journal of Agricultural Economics, 61*(2), 343–368.

Yuan, Z., Xiao, Y., & 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., & 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., & 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).

Zhang, X., & Chen, L. (2005). *Economic development at the village level*. Wu Han, China: Wuhan University Press (in Chinese).

Zhang, X., Chen, X., & Wang, J. (Eds.). (2004). *China rural reform and development*. Wu Han, China: Wuhan University Press (in Chinese).

Zhang, X., Yang, J., & Wang, S. (2011). China has reached the Lewis turning point. *China Economic Review, 22*(4), 542–554.

Zhao, X., & 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).

Zhu, H., Jin, F., & Li, R. (2002). *A study of the flood storage functions of poyang lake and flood damage reduction*. Beijing: Climatology Press (in Chinese).

Chapter 3
Assessing Human Well-Being in the Poyang Lake Region

Abstract A regional assessment of well-being is carried out for 298 townships (administrative units below counties and above villages) in the Poyang Lake Region. First, flood hazard zones are mapped, using an innovative approach based on a digital elevation model, GIS data on levee distribution, and historical data on lake levels. Then measures of exposure and sensitivity at the township level are derived, combining land-use data interpreted from remote sensing images and a population distribution map with the flood hazard zones. Socioeconomic variables from the 2000 census are chosen to best represent the three aspects of development: health, literacy, and income. The assessment indicates that development in the PLR overall is highly exposed and sensitive to flooding risk. Sensitivity is closely related to (and perhaps bound by) exposure, with both rising in according with proximity to the lake. The development level, however, is more closely associated with degree of urbanization, and higher development levels are found in townships closer to county capitals. There are significant variations in different aspects of human well-being among the townships. I discuss different sustainable development pathways for several types of townships and implications for government interventions.

Keywords Human well-being • Sustainable development • GIS • Land use • Quantitative assessment • Flood hazard

3.1 Mapping Flood Risk

Flood hazard is often described in terms of frequency of flooding over a specific period, for example, 50 or 100 years (Dunne and Leopold 1978). The frequency reflects the empirical probability of flooding in a particular location, often derived from historical records of past floods. Such records are usually aggregated at high levels of administrative units or based on point samples collected with insufficient frequency to provide detailed spatial variability of hazard over a large area.

It is possible to obtain a continuous spatial surface of flooding frequency if maps of flooding over a multiple-year period are available. Satellite-based remote sensing images provide an effective way to create maps of inundation over large areas

The material of this chapter was published in Applied Geography (Tian et al. 2015).

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0_3

(Deutsch et al. 1973; Rango and Solomonson 1974; Bhavsar 1984; Wang et al. 2002; Andreoli et al. 2007). However, they are relatively new and don't yet cover a 50-year period. Also the optical sensors cannot penetrate clouds, which nearly always accompany floods, so they are mainly used to observe the extent of flooding after the event itself.

An alternative approach is to model floods based on digital elevation models (DEMs). Because DEMs characterize the topographical basin in which a flood occurs, they provide important information on flood hazards. DEMs have been used in various ways to aid flood mapping and modeling, often in combination with other data, such as hydrological and hydraulic models, and satellite observations of the inundation extent (Correia et al. 1998; Liu and De Smedt 2005; Qi et al. 2009).

For this analysis, a DEM at 30-m resolution (Fig. 2.2) is combined with GIS data on levee location, height, and construction quality (Fig. 2.5), and annual high lake levels from 1951 to 2001 (Fig. 2.4) to map flood hazard zones in the Poyang Lake Region. Two elements are essential in determining the flood hazard: elevation and levee construction. The terrain around the lake forms a floodplain but rises farther away from the lake. The height and quality of the levees are important factors that affect the geographical variations of flood hazard, as are the varying land elevations.

A map of the 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 are used to adjust the DEM to characterize the terrain as modified by levee construction. Based on the adjusted elevations, historical high lake levels recorded at Hukou are used to produce a flooding frequency map. Flood hazard zones are then identified according to flooding probability.

In theory, levee protection is the technological equivalent of higher elevation. But because levees can fail, and their failure is a chief cause of flooding, this virtual height does not provide the same level of protection as natural elevation. I borrow the concept of discount rate from economics to discount the virtual height created by a levee based on its probability of failure. The modified elevation of a place behind a levee is computed as:

$$E' = E + (H - E) * R \tag{3.1}$$

Where E and E' are the DEM-based and modified elevations of a pixel respectively, H is the levee height and R is the discount rate, which is an (inverse) indicator of a levee's failure probability. Levee type is an important determinant of flood hazard and indicates how often a levee is expected to fail or be breached. The discount rates are as follows: 98% for crucial levees, 95% for major levees, 98% for flood storages, 90% for minor levees, and 80% for returned levees. These discount rates reflect the likelihood of levee failure. 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. Local scientists were consulted for choosing the discount rates.

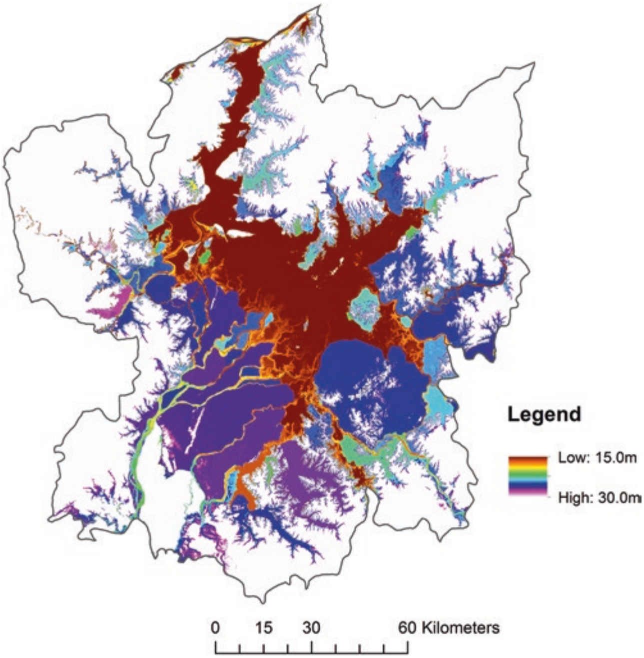


Fig. 3.1 Elevations in the Poyang Lake Region, modified to represent the effects of levees. The area in white is above 30 m

After the DEM is adjusted (Fig. 3.1), historical data on lake levels from 1951 to 2001 are used to generate a flooding frequency map. During this period, the historical high-water level reached 22.59 m at Hukou in 1998, and the lowest high-water level of 15.84 m occurred in 1972 (Jiang 2006; Qi et al. 2009). If the adjusted elevation of a place is lower than the high-water level of a year, it is counted as having flooded once. The total number of years in which the adjusted elevation of a place is lower than the high-water level is summarized to generate the flooding frequency over a 50-year period.

The flood frequency map is then classified to create flood hazard zones (Fig. 3.2) using the definitions described in Table 3.1. These flood hazard zones allow us to evaluate the spatial variability of flood risk, and serve as the basis for calculating exposure and sensitivity of human development to flooding.

3.2 Measuring Well-Being at the Township Level

The variables representing the three aspects of well-being at the township level are shown in Table 3.2. For the assessment, the five flood hazard zones defined in Table 3.1 are reclassified into three zones of high, medium, and low flood risk.

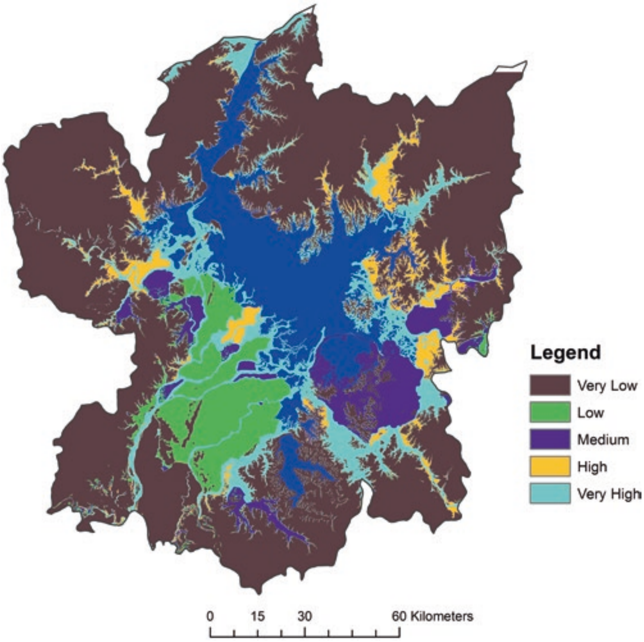


Fig. 3.2 Mapped flood hazard zones in the PLR, as defined in Table 3.1

Table 3.1 Definitions of flood hazard zones

Flood hazard zone	Flooding frequency over 50 years (F)	Interpretation
Very low risk	F = 0	Never flooded
Low risk	F = 1	Flooded once every 50 years
Medium risk	$1 < F \leq 5$	Flooded more than once every 50 years
High risk	$5 < F \leq 10$	Flooded more than once every 10 years
Very high risk	$F > 10$	Flooded more than once every 5 years

The high flood hazard zone now includes areas of high and very high flood risk, the low flood hazard zone includes areas of low and very low flood risk; the medium flood hazard zone remains the same.

Exposure is represented by the percentage of land in the high flood hazard zone, which reflects the biophysical environment in a township with respect to flood hazards. The percentages of people and farmland in the high flood hazard zone are used to represent the sensitivity of human development to flooding. These measures reflect the outcome of human-environment interactions and how human development can be affected by flooding. Unlike the measure of exposure (percentage of land in the high flood hazard zone), these measures of sensitivity are changeable.

Table 3.2 Summary of variables used in the regional assessment

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

Note: For those townships with missing land-use data, we used the sensitivity of population is used to represent the overall sensitivity of development to flooding

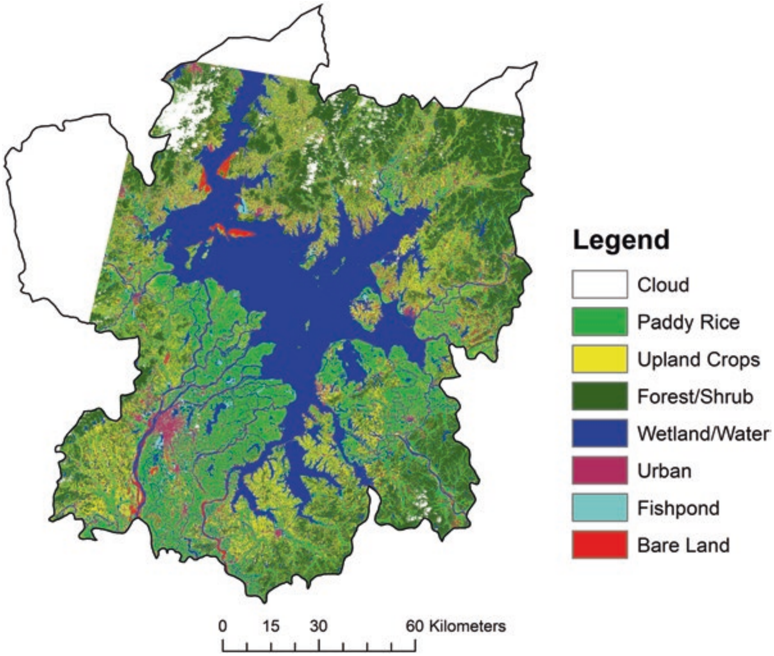


Fig. 3.3 Land-use land-cover map in the PLR, interpreted from Landsat 7 ETM+ images

The measures of exposure and sensitivity are calculated using the map of flood hazard zones, a population density map, a land-use map, and township boundaries within ArcGIS. The China Data Center at the University of Michigan provided this study a population density map at one square kilometer grid level and a geographic data layer that approximates township boundaries in the PLR. Further details on the creation of the population density map can be found in Tian et al. (2015).

A land cover layer is interpreted from a pair of Landsat 7 ETM+ images (path 121/row 40) on December 10, 1999 and July 5, 2000 (Jiang et al. 2008; Fig. 3.3). Because Landsat TM/ETM path 121/row 40 does not cover the entire study area, farmland data are collected for only 270 of the 298 townships in the PLR. The producer's accuracy and user's accuracy for farmland classification are, respectively, 82 and 94%; and further information on land cover data collection can be found in Jiang et al. (2008).

Three variables from the 2000 census data (provided by the China Data Center at the University of Michigan) are chosen to represent human development at the township level in the PLR. They are the closest match to UNDP's (1990–2014) human development measures in income, literacy, and life expectancy. Because income is not reported in the census, the number of households per thousand that spent at least 50,000CNY to build or purchase a house is used to capture economic development. The percentage of the population with at least a high school education and the number of deaths per thousand infants under 1 year old are 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 aspects of well-being provides a good understanding of relative levels of development, exposure, and sensitivity in the townships. 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.

3.3 Assessment Results

About one-third of the land and one-fifth of the farmland in the Poyang Lake Region are at risk of flooding more than once every 10 years (Table 3.3). Approximately one-quarter of the population lives in a location at risk of flooding more than once every 10 years (Table 3.3). These numbers suggest that development in the PLR overall is highly exposed and sensitive to flooding. However, there are large variations in the three aspects of well-being among the townships (Table 3.4).

Variables representing exposure and sensitivity exhibit similar spatial patterns, with both exposure and sensitivity correlating with proximity to the lake (Figs. 3.4 and 3.5). The percentage of land in the high flood hazard zone is negatively associated with the distance from Poyang Lake, with a correlation coefficient of −0.47. The percentage of population in the high flood hazard zone and the percentage of farmland in the high flood hazard zone are both significantly correlated with the percentage of land in the high flood hazard zone, with a correlation coefficient of 0.97 and 0.86, respectively. The relative level of sensitivity is identical to the relative level of exposure for most townships (247 townships), and only 17 townships have sensitivity one level lower than exposure (Table 3.5). These facts suggest that the sensitivity of development to flooding is affected by, or maybe confined to, exposure to some degree.

Variables representing development level do not appear to have a spatial pattern similar to that of exposure (Figs. 3.4 and 3.5), and the overall development level is not statistically associated with exposure, with a correlation coefficient of 0.02. There are some townships in which exposure and development influence the population in opposite directions. 14 townships have both exposure and development

Table 3.3 Land, population, and farmland in each flood hazard zone in the PLR

Flood hazard zone	Area of land (%)	Population (%)	Area of farmland (%)
Low risk	63.3	68.2	66.5
Medium risk	7.4	8.6	14.0
High risk	29.3	23.2	19.5
Total	19,874 km^2	7,955,966 persons	7,849 km^2

Table 3.4 Descriptive statistics of well-being measures

	Pct. land in the high hazard zone	Pct. people in the high hazard zone	Pct. farmland in the high hazard 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

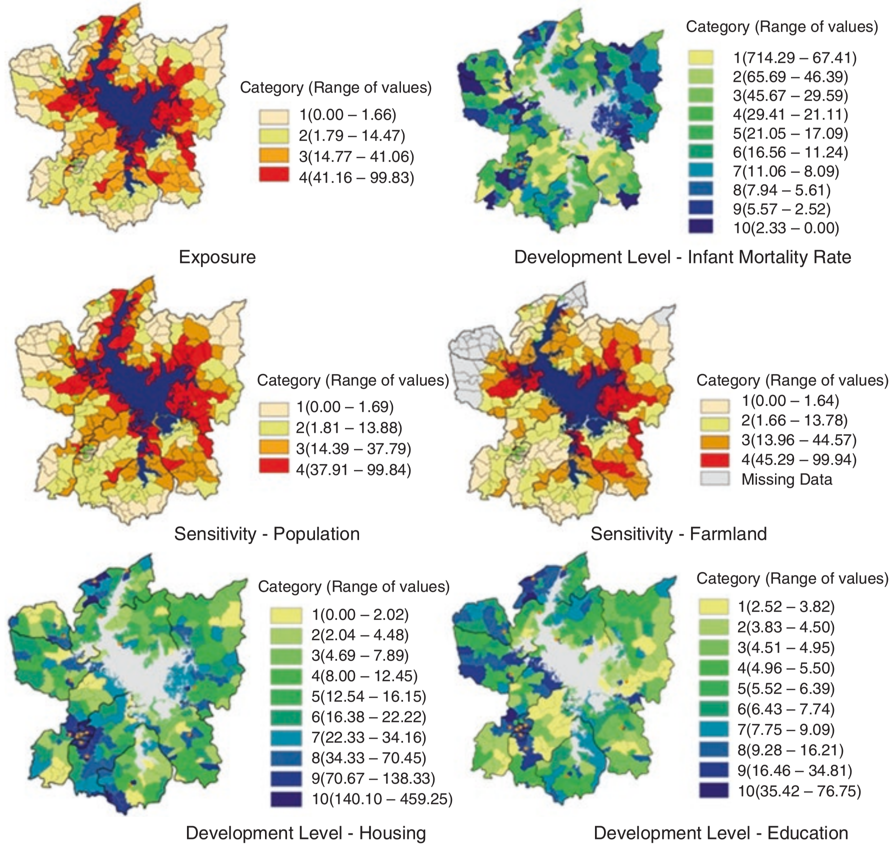


Fig. 3.4 Mapped patterns of each variable. The categories for the variables are defined in Table 3.2. Green or yellow dots indicate county capitals; the provincial capital, Nanchang, is in the lower left quadrant of each map, where a cluster of dots represent its districts

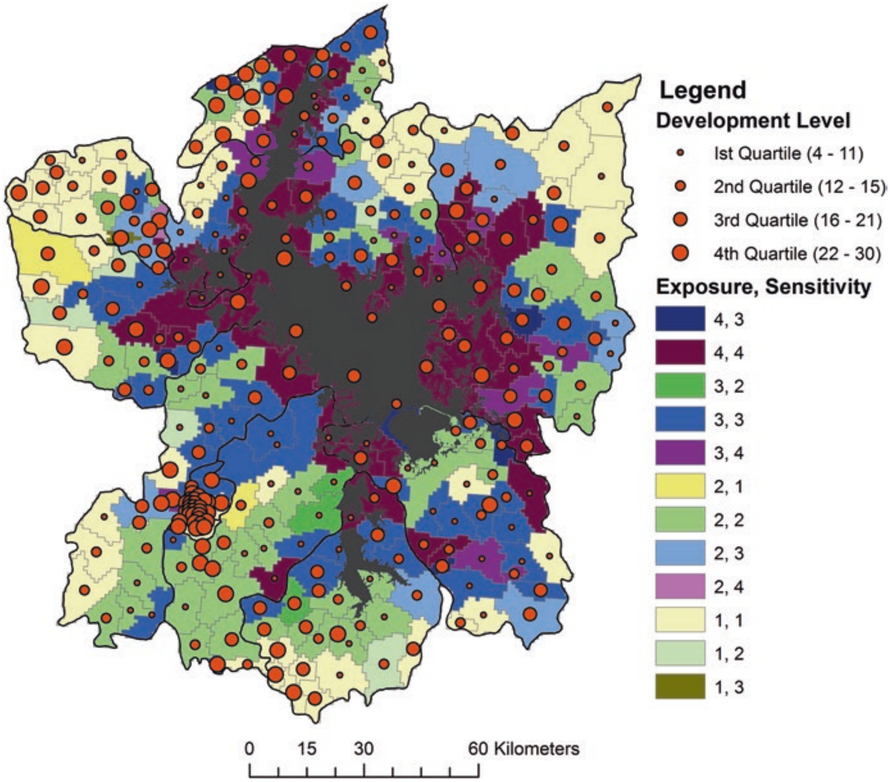


Fig. 3.5 Classification of townships according to the three aspects of well-being. The categories for exposure, sensitivity, and development level are defined in Table 3.2

levels in the lowest quartile, and 15 townships have both exposure and development levels in the highest quartile (Table 3.5).

Variations in development level among townships are more related to proximity to cities and degree of urbanization. Though the correlation between development level and distance to county capital are not statistically strong among all townships, with a correlation coefficient of 0.31, the mean distance to the county capital for townships in the highest quartile of development level is significantly smaller than that of townships in other quartiles, where $p < 0.001$. Development level and the percentage of rural population are negatively correlated, with a correlation coefficient of −0.61. The percentage of rural population alone explains 57% of the variation in development level among all townships.

Also note that the three measures of development in income, health, and education are not closely related to one another. The housing variable and the education variable are correlated to some degree, with a correlation coefficient of 0.56. But the

Table 3.5 Distribution of townships among quartiles of exposure, sensitivity, and development level

Exposure score	Sensitivity score (number of townships)	Development level (number of townships)			
		First quartile	Second quartile	Third quartile	Fourth 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**

Note: Boldface numbers represent township types that deserve particular attention

housing variable, with a correlation coefficient of −0.17, is not correlated with the health variable. This suggests that a higher level of economic achievement does not guarantee improved health, and that focusing only on economic growth may not be sufficient to increase overall human well-being.

3.4 Implications for Future Development and Policy Interventions

This assessment of development level, exposure, and sensitivity provides an overview of the state of development in the PLR and how it can be affected by flood hazards. More important, the assessment reveals large variations in the three aspects of well-being among the 298 townships. These variations suggest different sustainable development pathways and a need for different policy interventions to improve human well-being in the area. Several types of townships deserve particular attention, as shown in bold fonts in Table 3.5.

Townships with extremely high degrees of exposure and sensitivity, and low levels of development, could be candidates of the government's wetland restoration program. Many of these are quite near the lake (Fig. 3.5). The government initiative "returning farmland to lake" is a first step taken toward a more ecologically sound means of flood mitigation. This assessment provides some useful information for the government to move further in this direction.

Townships with extremely high degrees of exposure and sensitivity, and low levels of development, could also be candidate sites for natural reserves. The current natural reserves around Poyang Lake do not provide adequate wintering habitat for the endangered cranes, and need expansion (Bird Life International 2000; Kanai et al. 2002). For this purpose, additional information on local-scale variations in hydrology of Poyang Lake and wetland habitats should be combined with the measures here to prioritize the preserves.

For highly exposed townships whose populations are also extremely sensitive, policies that induce people to migrate out might be appropriate. Extremely high levels of exposure alone can reduce human well-being to such a low level that out-migration becomes perhaps the best solution, particularly when human life is threatened. However, given their long-established livelihoods and ties to a particular place, farmer households may find it difficult to leave their villages. Assisting them in finding new livelihoods in cities or elsewhere can be an important part of migration efforts. Such efforts could target future generations through education. Governments do need to respect the local people's right to choose, though. In 12 townships, 90% of both the land and people are in the high flood hazard zone, and in 5 of them, more than 95% of the land and people are in the high flood hazard zone.

Townships whose farmland is highly sensitive to flooding may consider alternative land uses developed by agricultural scientists, as described in Chap. 2, to reduce flood damage and increase land profitability. The information generated by this assessment can help government agencies target dissemination efforts to the townships that need them the most. 30 townships have more than 50% of their farmland in the high flood hazard zone; only 3 of them have less than 50% of their land in the high flood hazard zone. 13 townships have more than 80% of both their land and farmland in the high flood hazard zone.

Townships that are not highly exposed to flooding and have low levels of development need to examine the social system to look for ways to improve their development. Most of them are far from the lake (Fig. 3.5). 14 townships have both exposure and development levels in the lowest quartile. They are the "hotspots" and need further investigation into the causes for their low development in order to identify specific solutions.

Townships with degrees of sensitivity higher than exposure need to and can examine their development patterns to further reduce sensitivity. 34 townships belong to this category (Table 3.5). Finally, 12 townships have development, exposure, and sensitivity levels all in the highest quartile (Table 3.5). For development to become sustainable in these townships, strengthening the levee system is necessary, in addition to making appropriate adjustments to development.

This assessment has several limitations due to the paucity of township-level data. Direct measures of income would better capture the economic aspect of human development. The discussions on future development of several types of townships are limited due to a lack of further information about those townships. The accuracy of the assessment can be affected by errors resulting from the classification of remote sensing images. Because major errors associated with farmland classification are due to confusion of farmland with forest on the images (Jiang et al. 2008), the assessment accuracy for those townships that have significant forest coverage may suffer more than other townships.

An assessment using more recent data would generate a better understanding of the current situation. In another new study with Dr. Luguang Jiang at the Chinese Academy of Sciences, we use Landsat images to examine rice cropping changes around Poyang Lake. We find that from 2003 to 2013, the intensification of agricultural production, i.e., switch from one- to two-season rice, has occurred mostly in crucial and major polders, and that rice cultivation has been de-intensified within minor polders. This indicates that the potential impacts of flood hazards on agriculture have been reduced in the region. Rural income has been rising, though it is still relatively low. Overall, the region has been developing in the right direction.

3.5 Conclusions

This assessment suggests that development in the Poyang Lake Region overall is highly exposed and sensitive to flooding. Approximately one-fifth of the farmland and one-quarter of the population are situated in areas of high flood hazard, i.e., at risk of being flooded more than once every 10 years. The sensitivity of development to flooding at the township level is closely related to, and perhaps bound by, exposure, with both higher closer to the lake. The development level, however, is more closely associated with the degree of urbanization in a township. Higher development levels are also found in townships closer to county capitals. There are significant variations in the three aspects of well-being among 298 townships in the region. These variations indicate different sustainable development pathways and the need for different policy interventions for different townships.

References

Andreoli, R., Yesou, H., Li, J., & 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.

Bird Life International. (2000). *Threatened birds of the world*. Cambridge, UK: Bird Life Intl.
Correia, F. N., Rego, F. C., Saraiva, M. D. S., & Ramos, I. (1998). Coupling GIS with hydrologic and hydraulic flood modeling. *Water Resources Management, 12*, 229–249.
Deutsch, M., Ruggles, F., Guss, P., & Yost, E. (1973). Mapping the 1973 Mississippi Floods from the Earth Resource Technology Satellites. *Journal of the American Water Resources Association, 17*, 39–55.
Dunne, T., & Leopold, L. B. (1978). *Water in environmental planning*. New York: W. H. Freeman.
Jiang, L. (2006). *Flood risk and land use change in the wetland restoration area around Poyang Lake, China*. Ph.D. 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., & 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., & Higuchi, H. (2002). Migration routes and important resting areas of Siberian Cranes. *Biological Conservation, 106*, 339–346.
Liu, Y. B., & De Smedt, F. (2005). Flood modeling for complex terrain using GIS and remote sensed information. *Water Resources Management, 19*(5), 605–624.
Millennium Development Goals (MDG). (2008). Retrieved from http://siteresources.worldbank.org/DATASTATISTICS/Resources/MDGsOfficialList2008.pdf.
Qi, S., Brown, D. G., Tian, Q., Jiang, L., Zhao, T., & Bergen, K. M. (2009). Inundation extent and flood frequency mapping using LANDSAT imagery and digital elevation models. *GIScience and Remote Sensing, 46*(1), 101–127.
Rango, A., & Solomonson, V. V. (1974). Regional flood mapping from space. *Water Resources Research, 10*(3), 473–484.
Tian, Q., Brown, D. G., Bao, S., & Qi, S. (2015). Assessing and mapping human well-being for sustainable development amid flood hazards: Poyang Lake Region of China. *Applied Geography, 63*, 66–76.
UNDP. (1990–2014). *Human development report*. Retrieved from http://hdr.undp.org/en/global-reports.
Wang, Y., Colby, J. D., & Mulcahy, K. A. (2002). An efficient method for mapping flood extent in a coastal floodplain using Landsat TM and DEM data. *International Journal of Remote Sensing, 23*(18), 3681–3696.

Chapter 4
Understanding the Complex Processes Underlying Well-Being of Rural Households

Abstract An analysis of rural livelihoods is carried out to understand the micro- and macro-level processes that shape the well-being of rural households during urbanization. The analysis is based on quantitative surveys and qualitative interviews and field observations across eight villages around Poyang Lake. I examine rural households' livelihoods against the broad development background in China, and within their local environmental contexts, which also define their exposure to flood hazards. While urbanization has a positive effect on reducing the sensitivity of rural livelihoods to flooding, a variety of constraints, including some institutional factors and macro-level processes, confront rural households in developing viable livelihoods. I discuss how development programs and policy may simultaneously promote rural development and mitigate flood impacts in the Poyang Lake area.

Keywords Rural livelihoods • Rural-urban connection • Policy and institutions • Urbanization • Flood impact mitigation • Understanding processes

4.1 Micro- and Macro-level Processes Affecting Rural Livelihoods

Amid ongoing and accelerated urbanization in China, micro- and macro-level processes affect both the livelihood options available to rural households and choices they make (Fig. 4.1). First of all, rural households have individual characteristics; five types of capital—natural, human, social, financial, and physical—provide resources and assets for them to form livelihood strategies and affect their capabilities (Ellis 1998; Bebbington 1999).

A variety of local social and environmental factors can affect their options and choices. The biophysical environment largely determines the quality of their farmland and other natural resources, as well as the flood risk. A village's characteristics, especially its social capital and location relative to a small or large urban center, can

Part of the material from this chapter was published in the Journal of Rural Studies (Tian et al. 2016).

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0_4

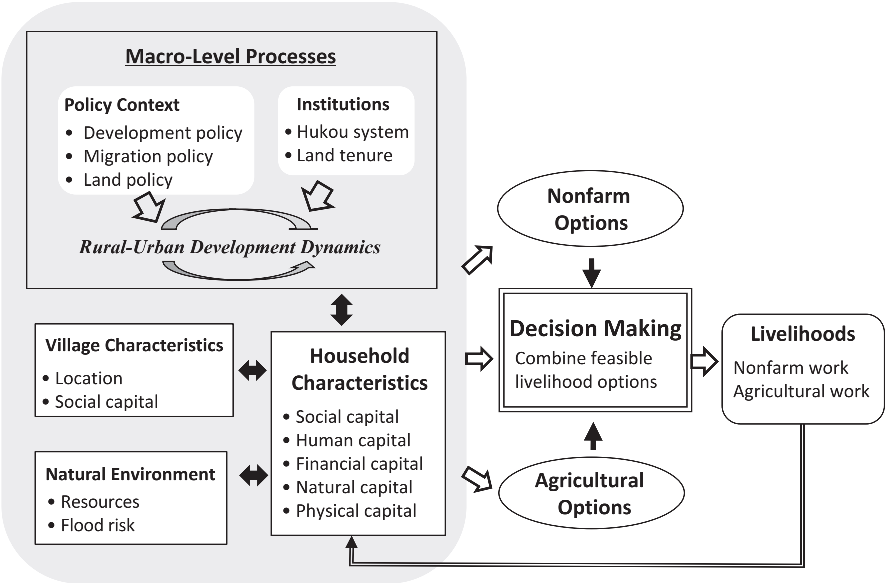


Fig. 4.1 Micro- and macro-level processes affecting rural livelihoods (Tian et al. 2016)

shape household livelihood options. These local factors interact with household characteristics to produce variations in livelihood strategies and outcomes.

Institutions and policy can also play an important role to affect or constrain rural household livelihood options, decisions, and development levels directly, or indirectly through influencing rural-urban development dynamics. The analysis in this chapter is intended to understand how household characteristics, and local and macro-level processes, interact to shape rural household livelihood options and choices, and ultimately the well-being of rural households.

4.2 Measuring Well-Being of Rural Households

Development at the household level is represented by income per capita. Low income is invariably the central issue for development in less developed areas. As I observed in the field, income often determines a farmer household's living standards. I also use the survey data to verify this observation throughout this analysis. Overall, income per capita is found to be a fairly good proxy for most aspects of development (Ray 1998).

I examine household income sources to understand the sensitivity of a household's livelihoods to flooding. Floods affect farm-based income—from crop cultivation, forestry, and livestock to fishing and aquaculture—more so than nonfarm income, such as wage- or salary-based migratory work and other business activities. The flood hazard zone in which a household is located reflects the degree to which the household is exposed to flooding, and I use it to examine the household's exposure to floods. These zones are defined in Chap. 3.

4.3 Household Surveys and Interviews

The analysis of rural livelihoods is based on surveys, interviews, and observations across eight villages around Poyang Lake. Primary surveys were conducted in 2007 during the Spring Festival (the Chinese New Year). The surveyed villages represent geographical and environmental variability in the Poyang Lake area (Table 4.1; Fig. 2.1); their distance to urban centers and flood risk are counted as major variables.

A comprehensive dataset about land use, livelihoods, and socio-demographic information for 192 households is compiled from the surveys (Tables 4.1, 4.2, and 4.3; Figs. 4.2 and 4.3). Data on crop cultivation and production are collected at the plot level. Demographic information, farmland endowment, education, social connections (in terms of government contacts), and income sources are collected directly or summarized for each household. All continuous variables are mean-centered for statistical analyses. Further details on survey data collection can be found in Tian et al. (2015). Note that the villages' real names are not used to protect their privacy.

Another visit to the surveyed villages, this time with a local assistant, took place in summer 2008, as a follow-up to the surveys. During this visit, I conducted formal and informal interviews with 49 farmer households, 10 village leaders, and 10 local government officials, 5 of whom worked at the county level and five at the township level (Table 4.1). We stayed with a household in villages ZJ, TJK, and HXL, spending 5–7 days with each, observing the daily life of villagers and engaging in informal conversations. We spent a half to a full day in each of the other five villages. In each village, we also visited the agricultural fields in the company of a farmer or village leader to familiarize ourselves with the natural environment. The photos that follow present some aspects of rural life in the villages (Fig. 4.4). The website http://mason.gmu.edu/~qtian2/ has more information about my visits to the villages and rural life around Poyang Lake.

The formal interviews include a series of questions designed based on a preliminary analysis of the survey data and informed by opinions of local scientists in Jiangxi. Our conversations with farmers are, however, not constrained by these preset questions; following Holstein and Gubrium's (1995) active interviewing approach, we seek in-depth understanding of how floods and other factors affect their livelihoods. Staying with farmer households offers many opportunities for informal conversations and observations, and gives us additional insights into their decision-making processes.

Table 4.1 Characteristics of 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	4,280.9	4,972.2	4,673.7	3,238.2	5,476.7	5,989.8	3,978.4	3,612.2
	Crop cultivation	1,803.9	338.5	1,202.9	1,162.4	466.4	2,674.4	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	1,444.4	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	1,681.7	1,257.6	3,037.9	1,593.7	3,011.9	1,051.1	1,903.3	2,366.3
	Salary-based	80.4	227.3	87.9	0.0	466.1	1,586.7	1,288.1	354.3
	Business	178.9	989.9	258.6	54.9	957.6	148.9	169.8	40.0
	Pct. nonfarm income	47.62	89.58	72.42	51.37	82.83	48.84	57.72	76.58

Loans	Avg. amount of loans	7,217.4	15,375	8,217.4	4,394.7	857.1	1,947.4	6,314.3	7,348.5
	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 0.067 ha

Table 4.2 Description of categorical variables at the household level

Variable name	Description	Frequency (n = 193)
Flood risk	1: In the very low hazard zone	35
	2: In the low hazard zone	23
	3: In the medium hazard zone	42
	4: In the high hazard zone	40
	5: In the very high hazard 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 motorcycle(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
	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	32,620	3,778	4,537	3,824.7
Farming income per capita	Including income from crop cultivation, forestry, livestock, fishing, aquaculture, and agricultural wages	0	15,000.0	1,028.0	1,665.0	2,102.0
Non-agricultural wage per capita	Income from non-agricultural wage-based migration work	0	9,400	1,600	1,973	2,210.9
Salary-based income per capita	Income from salary-based work	0	12,000	0.0	545.6	1,733.7
Business income per capita	Income from business activities	0	20,000	0.0	353.3	2,161.9
Pct. nonfarm income	Percentage of nonfarm 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 flat farmland	0	100.00	100.00	86.61	27.69

Note: All income measures are in CNY

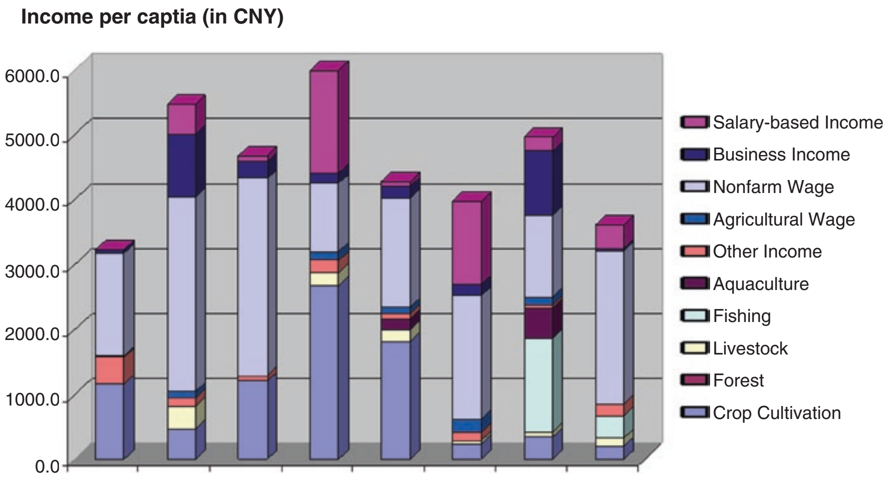


Fig. 4.2 Livelihoods and income composition in surveyed villages

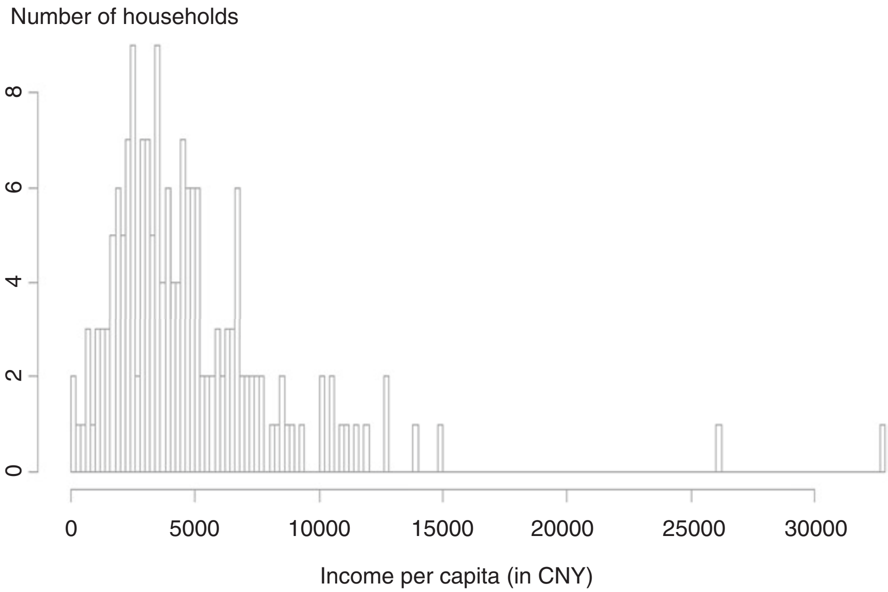


Fig. 4.3 Income distribution among surveyed households

4.4 The Use of Quantitative and Qualitative Analyses

I examine the differences in livelihood strategies across the surveyed villages and compare their natural environments, locations, and social characteristics to understand how these local factors affect the household livelihoods. Based on the

Fig. 4.4 Rural life in villages around Poyang Lake

variations in per capita income among surveyed households (Fig. 4.3), three groups of households with extreme income are identified. Group A has an extremely low development level, with per capita income below 1,000 CNY. Group B has an extremely high development level, with per capita income above 25,000 CNY. Group C has a high development level, with per capita income above 10,000 CNY, but below 15,000 CNY. In each group, I look at the livelihood profiles and household characteristics to analyze what makes a household better or worse off.

Finally, I turn to the majority of surveyed households and examine their decision making to illustrate various constraints they face in developing their livelihoods. While qualitative interviews and field observations allow a deeper understanding of their options and choices, the survey data complement and strengthen the qualitative understanding. The interviews also provide detailed information about crop-growth cycles, which allows me to examine how flood hazards affect agriculture in the region. Additionally, I use the household survey data to explore the relationships between development level, sensitivity, and exposure.

4.5 Results

4.5.1 Differences among Villages and Local Social, Environmental Factors

The surveyed villages differ in mean income per capita (Appendix: Fig. 4.1), but the differences are not statistically significant due to large variations among the households within those villages (Appendix: Fig. 4.2). Income per capita at the village level does not consistently correlate with exposure to flood risk; those with lower exposure do not all have higher mean income per capita, and those with higher exposure do not all have lower mean income per capita (Table 4.1). In fact, villages ZJQ and ZJYM have higher mean income per capita than all other villages *and* a higher exposure than most.

Certain characteristics of a village, however, do provide advantages or disadvantages for the development of household livelihoods. Being located near an urban center, as are ZJQ and ZJYM, provides market accessibility to high-return income options, such as raising livestock or commercial vegetable production, as well as opportunities for seasonal nonfarm work. Households located near urban centers can combine these options to earn a good income without having to leave their homes (see also Veeck and Pannell 1989).

Villages endowed with special natural resources can use these resources to improve income quickly. For example, villagers in TJK made good money from river sand mining until the government began to regulate the practice in the Poyang Lake area amid concerns about environmental issues. Yet villages like TJK, with access to special types of natural resources, are few. While households in villages with rich, highly productive farmland, like ZJ, benefit from combining good farming income with wages from migratory work, households in farmland-poor villages, like HXL, have to leave their homes to seek migratory work. These advantages or disadvantages in natural resources are largely fixed, based on geographical locations.

The leadership of a capable farmer or household can play an important role in shaping the livelihoods of all the village households. Most villagers find migratory work through other farmers in their village (or, in some cases, through relatives). Therefore, the kind of migratory work available to them, 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, their success can inspire other households or create job opportunities for others. Our conversations with local officials reveal that even when government agencies choose villages for special development projects, they look at villagers' initiative; their experiences show that a project is more likely to succeed if villagers demonstrate initiative and have the capacity to carry out the project.

Strong leadership can enhance a village's social capital. Its absence is often associated with a village's low development levels, and low morale, which reinforces a negative spiral. 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). Such leadership was generally absent in the villages we visited, and can be enhanced.

4.5.2 *Low-Income Households*

The eight households with extremely low incomes share several characteristics (Table 4.4). They all rely completely on crop cultivation, and their income from crop cultivation is very low. They have very low education levels, generally only an elementary school education, with illiteracy not uncommon. Most have no government contacts. Four of the households consist of old couples who cannot do migratory work and barely get by growing subsistence crops. When an elderly couple has no sons to provide financial support, their household is called *Wu Bo Hu*. The *Wu Bo*

Table 4.4 Group A: households with extremely low income

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	1,000	1,475	1,600	3,420	1,500
Nonfarm income	0	0	0	0	0	0	0	0
Motorcycle 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

Hu receives some governmental assistance, but the amount is small and insufficient for a comfortable life.

The living standards of the low-income households are also very low. These villagers still live in mud or brick houses, while most households have houses made of reinforced concrete. They own no air conditioners, refrigerators, cell phones, motorcycles, or computers. They are found across seven of the eight surveyed villages, suggesting that extremely low development at the household level does not correlate with location or flood risk.

4.5.3 High-Income Households and Successful Livelihood Strategies

The top two households with extremely high income both make significant money from business (Table 4.5). The remaining high-income households, however, have mixed livelihood profiles (Table 4.6). All these households with high income enjoy

Table 4.5 Group B: households with extremely high income

Variable	H9	H10
Village ID	41	15
Flood risk	5	4
Close2City	0	1
Income per capita	32,625	26,163
Total income	130,500	104,650
Nonfarm income	84,500	103,000
Farming income	46,000	1,650
Agricultural wage	0	0
Non-agricultural wage	0	0
Business income	80,000	75,000
Salary-based income	4,500	28,000
Motorcycle 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 high income

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	12,650	12,625	15,000	14,000	11,810	11,520	11,061	10,805	10,500	10,418	10,175	10,050
Total income	50,600	50,500	60,000	42,000	47,240	57,600	66,364	75,634	42,000	41,670	40,700	40,200
Nonfarm income	46,000	48,000	0	20,000	46,000	57,600	56,400	65,200	12,000	36,000	15,600	0
Farming income	4,600	2,500	60,000	22,000	1,240	0	9,964	10,434	30,000	5,670	25,100	40,200
Agricultural wage	0	0	0	0	0	0	0	0	0	0	0	7000
Non-agricultural wage	10,000	0	0	20,000	15,000	9600	56,400	29,200	0	36,000	0	0
Business income	0	0	0	0	0	0	0	36,000	0	0	15,600	0
Salary-based income	36,000	48,000	0	0	31,000	48,000	0	0	12,000	0	0	0
Motorcycle 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

relatively good living conditions. The top two households own air conditioners. Many of the high-income households own motorcycles, cell phones, and houses built of reinforced concrete. Half of them have refrigerators, and two own computers. They are distributed across all eight surveyed villages, suggesting that high development at the household level does not correlate with location or flood risk.

The livelihoods of these high-income households suggest that each of the four livelihood profiles as shown in Table 4.6 can lead to high development levels: (I) diversified near-home; (II) business-oriented high-return; (III) farming-based; and (IV) combined migratory work and farming. Certain household characteristics and some local factors are important for the success of these profiles (Table 4.7).

Among the wealthiest households are those that have success in business (Table 4.5). These households are few and appear to share a special kind of capability: they are willing to take risk. All the interviewed farmers seem to understand that high economic returns involve high risks, and some farmers are able to share suc-

Table 4.7 Household characteristics, local factors, and successful livelihoods

Livelihood profile	Sub-type	Total labor	Education	Risk taking	Hard working	Social status and connections	Other factors
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 rice production			*	***	**	Good farmland resources
IV. Combined migratory work and farming profile	Salary-based work as the major income source	**	***			*	
	Wage-based migratory work as the major income source	***	**				

Note: The number of * indicates the degree of importance cess stories of risk takers. But very few of them are willing or able to assume such risks themselves.

Social connections are important for finding business opportunities and obtaining investment capital. Many of the business-oriented households lacked initial investment capital and borrowed money from friends, relatives, or banks to start their businesses. In interviews, farmers often use the term *Men Lu*. They explain that their bad situations have resulted from a lack of *Men Lu* and attribute the success of some other households to their possessing *Men Lu*. *Men* means "door" and *Lu* means "road." The term *Men Lu* can be best understood in English as options that come through social connections.

As a special form of social connection, government contacts can provide access to information, help obtain bank loans, and sometimes offer business opportunities directly. More households with business income and bank loans have government contacts than do those that lack business income or bank loans (Appendix: Table 4.1). Business-oriented households do not necessarily have very high levels of education (Table 4.5), and there is no significant difference in business income among three education levels (Appendix: Table 4.2). Business-oriented households do not necessarily have large amount of labor either (Table 4.5) because they can and do often hire laborers.

Two common types of households are successful in creating a diversified near-home livelihood: those in villages near an urban center and those with a member who is a village leader (Table 4.6). The location of a village near urban centers facilitates the development of successful, diversified livelihoods through combining vegetable cultivation, livestock production, and near-home nonfarm work.

Villages are the lowest level of administrative divisions of China. Village leaders are appointed by higher-level administrative units or are often now elected by villagers. As the head of a village, village leaders usually have better connections with local government officials. These connections and a leader's status in the village are important for acquiring contracts on special, often scarce resources, such as fish ponds. The village leaders are also better informed about the outside world and more aware of business opportunities.

Households with a farming-based livelihood profile can achieve high incomes through vegetable production or larger-scale rice cultivation (Table 4.6). These households are commonly hard working, in the sense that farmers must use great physical strength and tolerate all kinds of weather. Farming in the surveyed villages is mostly accomplished with human labor, although rice harvesting by machinery has been widely adopted in relatively flat areas.

Location near an urban center provides local market accessibility and facilitates vegetable production. There are success stories of commercial vegetable production in places far from any urban center, but these scenarios take extraordinary leadership and collective action. To form a scale of production large enough, for example, it is necessary to convert farmland over large areas—often including a whole village, town, or even a county—to vegetable fields. Sales channels and transportation must be arranged and coordinated for all the producers.

Living in an area with rich farmland makes it relatively easy for a household to acquire farmland, facilitating rice cultivation at larger scales. Social connections are, in general, useful for farmers to obtain land rental contracts. Some farmers have managed to contract large areas of farmland for rice cultivation in villages other than their own, and for these farmers, the social connections are even more important.

Education and labor amount are most important for the success of households with the combined farming and nonfarm work incomes (Table 4.6). Education plays a large role in influencing nonfarm income. The migrant workers usually earn higher incomes from salary-based jobs than from wage-based work, but salary-based jobs require higher levels of education. Migrant workers with low education levels often do temporary wage-based jobs that involve hard labor or poor working environments. The survey data show that households with high school education (and higher) on average have higher salary-based income, whereas households with elementary education (or below) have lower income from migratory work (Appendix: Table 4.2). Wages for migratory work do not vary significantly, and more nonfarm income can be accrued if more members participate in migratory work.

4.5.4 Most Households and Constraints on Rural Livelihoods

Based on a regression analysis, per capita income, for the majority of surveyed households, is significantly associated with farmland area, demographic composition, education, number of members participating in wage-based migratory work, and whether a household has salary-based income or government contacts (Table 4.8). The fact that farmland area per capita is a significant factor suggests that farming is still an important component of rural livelihoods for most households, and farmland resources contribute to some between-household variations in per capita income.

Having children but no older people in the household (who can care for children) negatively correlates with per capita income. In such cases, parents may have to stay on the farm, though they could make more money doing urban migratory work. I have discussed the role of education and the differences between wage- and salary-based nonfarm work in Sect. 4.5.3. Government contacts can help secure salary-based jobs, in addition to providing access to information, bank loans, and business opportunities, as discussed in Sect. 4.5.3. A larger proportion of surveyed households with salary-based income have government contacts (Appendix: Table 4.1).

For most households, income per capita is not associated with location or flood risk (Appendix: Table 4.3). Their income largely correlates with other aspects of living conditions (Appendix: Table 4.4). Motorcycles are becoming a common transportation tool for most of them. Households that own computers or air conditioners are few (Table 4.2), and they have relatively high income.

These findings are consistent with the analysis of extreme-income households. In fact, most households rely on a combination of farming with nonfarm work, and have a livelihood profile IV. They execute it to varying degrees of success, depend-

Table 4.8 Linear regression results

Category	Independent variable	Excluding all high-income households		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 migratory 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: *p-value ≤ 0.05, **p-value ≤ 0.001, ***p-value ≤ 0.1, ****p-value ≤ 0.01

ing on their characteristics in education, demographics, social connections, and farmland resources. Those high-income households are able to achieve higher levels of development because they have advantages in some of these factors. On the other hand, a negative combination of these factors lead to livelihoods dependent on crop cultivation and low levels of development for extreme low-income households (see also Glauben et al. 2012).

These variations in livelihood options, strategies, and development levels among rural households mostly result from the interactions between household characteristics, village characteristics, and local environmental factors (Fig. 4.1). While local biophysical environments and certain village characteristics provide advantages or disadvantages for the development of rural livelihoods, individual households are not totally confined by them, as demonstrated by those high-income households.

In general, human capital (especially education) and social capital (connections) are most important among a household's five types of capital. They shape a household's feasible options and determine the outcomes of its livelihood strategy. They also affect how successfully the household can acquire additional farmland and accumulate financial capital.

The development of household livelihoods is also path dependent, and the outcomes of a household's livelihood strategy reinforce its characteristics and capabilities over time (Fig. 4.1). Some households in the villages, through their accumulation of investment capital during the early period of economic reforms, are now able to take risks to further diversify their economic activities. Poor households tend to be more cautious about borrowing money to invest in high-return livelihoods, are less likely to seek loans, and more likely to maintain traditional low-return livelihoods,

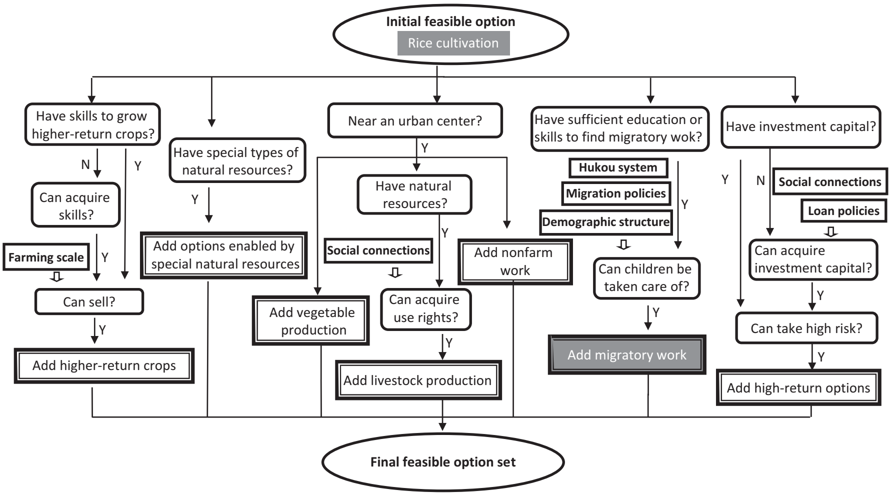


Fig. 4.5 Livelihood options and constraints on rural livelihoods (Tian et al. 2016)

thus falling into a poverty trap. Without external interventions, it will be difficult for these households to break the poverty cycle.

The interviews and field observations suggest that farmer households in the Poyang Lake Region are well informed about possible land-use and livelihood options, and able to articulate the costs and benefits associated with them, though they do not always have the assets or capabilities to implement them (Tian et al. 2015). The majority of the surveyed households are constrained in terms of feasible options (Fig. 4.5).

Most of the surveyed households do not live near an urban center or in a village endowed with special natural resources. The majority do not have government contacts or investment capital for high-return livelihoods, such as business; nor can they take the associated financial risk. Constrained by relatively low education, migrant workers typically seek work in the labor-intensive industrial sector and perform low-paying nonfarm jobs. In addition, their small farms produce low economic returns from crop cultivation, making it less likely that they can improve their incomes.

The increase in wages of migrant workers is slow also because the urban job market is flooded with a large rural migrant population. Some scholars use the theory of Unlimited Supply of Labor (Lewis 1954) to explain the slow wage growth for migrant workers in China, and argue that China now may have passed the "Lewis Point" (Cai 2010; Yao and Zhang 2010; Zhang et al. 2011).

In addition to the direct consequence of low agricultural income, the small farmland size constrains rural livelihoods in other important ways. Small farms cannot adopt higher-value crop types because in a free-market economy, farmer households face difficulty finding sales channels for their alternative small-scale production (Fig. 4.5). The small farmland size also discourages them from investing in agriculture, further preventing a rise in agricultural output (see also Tan et al. 2010). Across the surveyed villages (excepting ZJ, which has rich farmland), most adults are away from home doing migratory work, and the people we frequently see are the elderly, children, and some women; the overall effort in crop cultivation is low.

Though households can acquire additional farmland in land rental markets, most land rental contracts are privately negotiated, of short duration, and usually renewed on a yearly basis. The insecurity inherent in these short-term informal contracts discourages land exchanges. Some farmers in the surveyed villages say they would like to rent more farmland and specialize in agriculture, but they worry that the households to which the farmland was initially assigned may take back the rental land if they see improved productivity.

The *hukou* registration system affects not just the welfare and well-being of migrant workers in cities (Wong et al. 2007; Yin 2008). It can also constrain livelihood options for rural households (Fig. 4.5). As discussed earlier, when parents cannot find the means to take care of their young children, they cannot work in cities. Additionally, because of the differentiation of urban and rural *hukou*, migrant workers in the cities lack the same social security and benefits as urban populations and therefore regard farmland as their chief social safety net (see also Liu et al. 2014). This prevents those households that do well in cities from releasing their farmland to other households that want to specialize in agriculture. Across the surveyed villages, there are unoccupied new houses; their owners work somewhere else as migrants, but intend to come back and live in the village later. The recent *hukou* reform is expected to change this situation, which I will discuss in Sect. 4.6.1.

While low education and a lack of social capital and collective action all contribute to the average low levels of rural income, the constraints associated with institutional factors and macro-level processes cannot be resolved by individual households.

4.5.5 Sensitivity to Flooding and Inequality in Flood Impacts

The livelihoods of most households are not greatly affected by flooding because of their participation in the urban economy. Income diversity exists across all the surveyed villages (Table 4.1; Fig. 4.2); on average, more than half of the total income is from nonfarm sources (Table 4.3). And the households that have experienced flooding more frequently in the past include greater proportions of nonfarm income (Tian and Lemos in review; Appendix: Table 4.5). But poor households are most affected by flood hazards because their crop-cultivation-dependent livelihoods are highly sensitive to flooding.

Commercial vegetable production and larger-scale rice cultivation appear to be most sensitive to flooding. However, the households that have these two types of livelihoods are not likely to be much affected by flood hazards for the following reasons. Commercial vegetable production is usually practiced in villages near an urban center. Larger-scale rice cultivation is often found in areas with rich, highly productive farmland—these are major agricultural production centers. The urban centers and major agricultural areas in the PLR are protected by high-quality levees built and maintained by the government. The survey data also show that the households whose major income is from farming in general have experienced flood events infrequently (Tian and Lemos in review).

Flood impacts on agriculture also vary across locations. Agriculture in the PLR appears 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 suffer heavy damage when severe floods occur in July. The early rice harvest can be reduced or wiped out, and the late rice planting season missed if floodwaters remain for lengthy periods. However, the villages with rich, productive farmland, again, are the major rice production centers protected by well-built levees. Consequently, the sensitivity of their agricultural production to flooding is low. Villages with poor farmland are usually protected by low-quality levees and show a high sensitivity. More generally, agriculture in the high flood hazard zone is sensitive to flooding; according to the assessment in Chap. 3, 21.6% of farmland in the region lies in the high flood hazard zone.

4.6 Reflections on Policy

4.6.1 Urbanization and Rural Development

This analysis has demonstrated that the broader development context can significantly affect rural livelihoods. Development policy in general needs to look at rural development as an integrative, endogenous part of overall development, and guide urbanization to benefit rural households. Rural households make livelihood decisions also according to their own characteristics and local contexts. There are multiple paths to successful livelihoods, and we can expect that they will continue to develop their livelihoods along various paths. While some households may eventually exit or specialize in agriculture, others are likely to maintain rural and urban mixed livelihoods.

The stage of urbanization can be measured by the proportions of rural households performing urban work, agricultural work, and combined farm/nonfarm work, and how their respective incomes show improvement (Fig. 4.6). As urbanization increases, so too will the proportion of households that perform urban work. We may consider urbanization successful if at the end of this process, the income for all types of households is comparable to urban household income. Using such a systems perspective, we can assess our progress at any given time and learn useful insights for steering urbanization toward this desired final state.

Given the limited farmland resources and large rural populations, it is not difficult to understand, and most scholars agree, that increasing rural income will be dependent on nonfarm employment, and that the industrial sector is the engine driv-

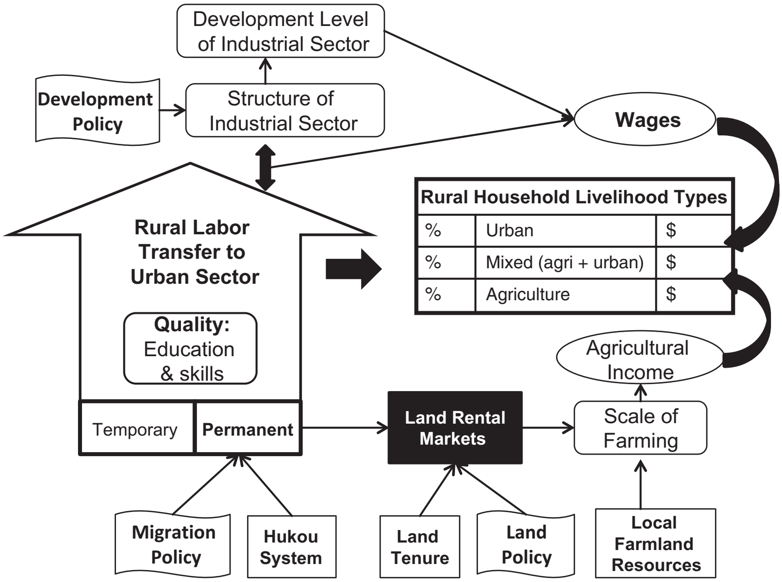


Fig. 4.6 Policy, institutions, and rural-urban development dynamics (Tian et al. 2016)

ing overall economic growth (Huang and Peng 2007). But the amount of rural labor transferring to the urban sector must be appropriate for that sector's development level, and policies that strive to promote industrial development should consider the quality and quantity of rural labor to facilitate rural labor transfer (Fig. 4.6). This would likely promote a linked, balanced growth of both sectors, which is essential for all rural households to increase incomes regardless of their livelihood types (see also Nurkse 1961; Johnston and Mellor 1961)—as the industrial sector grows and employs more rural migrants who make permanent homes in the city, households that stay in the countryside will be able to enlarge their farming operations, improving both agricultural production and income (Fig. 4.6).

Development, migration, and land policies can work synergistically to foster such healthy urban-rural development dynamics to lift macro-level constraints and facilitate rural households developing robust livelihoods through different paths. *Hukou* and land reform, farmland consolidation, and urban planning all play a part and must be considered together from this system's perspective.

The government's new migration policy that moves away from the *hukou* system toward a residency registration system is timely. This addresses the social unfairness inherent in *hukou*, especially for younger generations from rural areas because it will give them the same opportunities as they get a college education and compete for employment in the cities. Meanwhile, the government can use the point-awarding system to guide migration so as to avoid some of the potential undesirable outcomes of migration.

While *hukou* is associated with several issues in rural development, as discussed earlier, there is one major concern about the elimination of *hukou*—it could lead to an overflow of migrant workers to large cities, where labor absorption capabilities are limited. This would disturb the overall development dynamics (Fig. 4.6), and could lead to the rural poor becoming urban poor, a phenomenon that has been observed in some other developing countries (Dandekar 1997; Jellinek 1997; Anjaria 2006; Davis 2006).

The new residency registration system is an effective, flexible way to influence migration and urban growth. Because of the tough point requirements in larger cities, many migrant workers are more likely to settle in smaller cities; this can potentially encourage economic growth and increase urbanization in these cities. Farmers may also find it relatively easy to adapt to urban life if they settle in smaller cities near their villages.

The growth in smaller cities can also create near-home, nonfarm work opportunities and expand high-return livelihood options to more farmer households, which would improve their overall livelihoods. The industrial development in smaller cities may focus on activities that suit the natural environment and integrate agriculture and local culture.

Closely related to the new migration policy is China's initiative on the development of urban clusters to drive economic growth through urbanization, and to influence the pattern of migration. Urban clusters usually include one or two nucleus cities and networks of cities with well-connected transportation systems across provincial boundaries. The Perl River Delta (around Guangzhou and Shenzhen) and Beijing-Tianjin-Hebei (around Beijing and Tianjin) are among those early city clusters. Currently 11 city clusters exist mostly in the eastern regions,

China plans to increase this number to 19 by 2020, according to the country's 11th 5-year plan (2014–2020). The new clusters under development are also intended to promote economic growth in central China. The middle reaches of the Yangtze River is among those new clusters under development. It includes Hubei Province, Hunan Province, and Jiangxi Province, covering a total of 3,170,000 km^2. This will affect rural development and migration patterns in the zone that includes the PLR.

From the systems perspective, the development of urban clusters and the new migration policy can, and I expect them to, synergistically contribute to healthy urban-rural development dynamics. However, the scale of Chinese urban clusters is unprecedented and will likely create challenges for infrastructure and governance. How smaller cities are integrated with these urban clusters is not clear. The spatial configuration of urban centers at different scales can have important implications for both rural and urban development in the long run. The effects of these urban development and migration policies remain to be seen.

In the agricultural sector, the government should continue its efforts in farmland consolidation. The government's policy guidelines for farmland consolidation through exchanges in land rental markets are sound in principle. Providing special support to large farms can increase scales of farming operations, and this, together with the *hukou* reform and urban development plans, will likely lead to linked growth of the agricultural and industrial sectors. But the government needs also to ensure that the degree of farmland concentration is in accord with the amount of labor employed in the industrial sector.

Another approach to farmland consolidation could be to subsidize households that subcontract their farmland under long-term formal contracts. Coupled with the new migration policy that relaxes and eliminates *hukou*, this approach could encourage households that do well in cities to exit agriculture. In the next chapter, I use an agent-based computer model to explore the potential effects of such a policy in comparison to existing subsidies for rice growers and large farms.

Besides economic development, further improvements in social and cultural development are desirable in rural areas. The "building a new countryside" initiative has already produced observable effects on improving physical infrastructure and cultural life in some of the villages we visited. As the macro economy grows, the government may broaden the benefits of current health care and social welfare systems in the countryside. This is also an effective way to share the fruits of economic reforms with rural populations, whose interests have previously been compromised for urban development.

Land tenure has been a subject of debate among Chinese scholars (Li and Li 1989; Wei 1989; Chi 2000; Dong 2008); some argue that privatization is necessary to secure land rights for rural households and solve the Three Rural Issues, namely agriculture, farmers, and rural areas (see Palomar 2002; Zhang 2002; Liu and Han 2006). However, privatization of land could introduce a sudden change to the overall development dynamics and may not necessarily benefit farmer households (Fig. 4.6).

Under a private-property regime, households that do well in cities could instead hire labor to manage their farmland and may not release farmland to other households. Poor households that lack other viable livelihoods may be forced to sell their land for short-term gain, ending up becoming urban poor or agricultural laborers. Thus there would likely be a rise in inequality. Furthermore, it may not be a viable option for most households to use farmland as collateral to obtain bank loans for higher-return livelihoods—very few of them can take such risks and their holdings are too small.

Empirical evidence from the developing world shows that property rights titling is not always beneficial for development, and has in fact failed to deliver the benefits claimed by its proponents (e.g., De Soto 2000). It has sometimes even harmed the poor (Gilbert 2002; Cousins et al. 2005; Payne et al. 2009; Sjaastad and Cousins 2009; Domeher and Abdulai 2012). For example, in Latin American countries where more complete neoliberal policies have been implemented, economic growth has not led to significant poverty reduction; many smallholder farmers remain poor, and deep inequality persists (Berdegué and Fuentealba 2011).

A major problem associated with the current land tenure in China is land requisition by local governments (often for such purposes as industrial development). This can cause rural households to lose their land-based livelihoods, and in some cases, rural households are not compensated appropriately (Liu et al. 2014). Laws that specify and protect rural households' land rights are in place. The government must strengthen the enforcement of these laws. Issuance of land certificates to farmer households and extensions of their land contract periods will help strengthen farmer households' land rights; the insecurity of rental land could be remedied by long-term formal contracts.

4.6.2 Flood Impacts and Equitable, Sustainable Development

Development programs and policies may simultaneously promote human development and mitigate flood impacts in the Poyang Lake area in several ways. As noted, facilitating urbanization to benefit rural households could continue to improve rural income and reduce the dependence of rural livelihoods on agriculture, especially for households with high exposure to flooding. Encouraging larger-scale farming operations could also help make more feasible the land-use practices developed by agricultural scientists that utilize spatial planning to increase land profitability and reduce flood damage.

Poverty reduction programs may focus on enhancing the capabilities of poor households through education and training to help them develop diversified livelihoods. This would not only improve their livelihoods but also reduce their dependence on crop cultivation. Providing better welfare to rural populations in general, and the elderly in particular, could enhance their resources to cope with flood impacts as well.

Villages with poor farmland resources face greater challenges for development than other villages. Their poor farmland limits agricultural output. Furthermore, their agricultural production is highly sensitive to flooding because of poor levee protection. Many village households would probably be better off seeking urban-based livelihoods. The Jiangxi provincial and local governments could provide assistance to these households in establishing secure urban livelihoods. This could also address the issue of inequality in natural resources that is increased by the government's interventions on levee construction.

4.7 Conclusions

This analysis of rural livelihoods shows that the level of income and well-being of a household is largely determined by its livelihood strategy and how successfully the household executes that strategy. Four major livelihood profiles are identified using the survey data: (I) diversified near-home; (II) business-oriented; (III) farming-based; and (IV) combined migratory work and farming. Each of these can lead to high income if a household possesses certain characteristics, and some of these strategies are facilitated by local farmland resources or location near urban centers.

The majority of rural households have limited feasible options and rely on income from migratory work and farming. Low education, and lack of village social capital and collective action, are major constraints for most households.

Rural-urban development dynamics and institutional arrangements can also constrain rural livelihoods. In addition to the direct consequence of low agricultural income, the small farm size discourages farmer households from investing in agriculture. Nor can they easily alter traditional rice cultivation for higher-value crops because of the small production scale. The *hukou* system affected or affects not only the well-being of migrant workers in cities; coupled with the insecure rights for rental farmland inherent in informal short-term rental contracts, it discouraged or discourages land exchanges, further limiting the potential for rural households to raise their incomes through larger farming operations.

Rural livelihoods in the Poyang Lake area are not greatly affected by flooding due to large proportions of nonfarm income. Farmer household incomes are not associated with their flood risk. But the poor households whose livelihoods are highly dependent on crop cultivation are most affected. Although current agricultural practices appear sensitive to flooding, the degree to which the agricultural system is affected by flood hazards varies from village to village. Those villages with poor farmland face greater challenges for development. Their poor farmland limits agricultural output, and their agricultural production is also highly sensitive to flooding. Urbanization, in general, has a positive effect on improving rural livelihoods and reducing flood impacts, especially for households with poor farmland and high flood risks.

To ensure that rural households benefit from urbanization, national policy needs to foster healthy rural-urban development dynamics, and it is vitally important to promote the simultaneous growth of the agricultural and industrial sectors. The slow growth of rural income and rural-urban gaps are more likely resolved gradually and steadily through the linked growth of both sectors: As the industrial sector grows, more rural labor will be employed in that sector and earn higher wages; households in the countryside can accordingly enlarge their farming operations, improving agricultural income. The growth in nonfarm income and upscaling of farming operations in general will mitigate flood impacts on rural livelihoods in the PLR.

China's recent policy developments, i.e., *hukou* reform that shifts toward residency registration systems in cities, the focus on developing urban clusters rather than large monocentric cities, the issuance of land-use rights certificates to farmer households and extensions of their land contract periods, and special supports for large farms, seem to be appropriate. These will likely contribute synergistically to healthy rural-urban development dynamics and shape urbanization and rural development to produce positive outcomes.

Poverty reduction programs should aim at enhancing households' capabilities and assisting them in developing diversified livelihoods. This would also reduce flood impacts on the livelihoods of poor households in the PLR. The Jiangxi government may provide additional assistance to households in villages with poor farmland resources and high flood risks in establishing secure urban livelihoods. In the high flood hazard zone more generally, the Jiangxi government may increase its efforts in researching and promoting alternative land uses and livelihoods that suit specific biophysical environments.

References

Anjaria, J. S. (2006). Street hawkers and public space in Mumbai. *Economic and Political Weekly*, 2140–2146.

Bebbington, A. (1999). Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. *World Development, 27*, 2021–2044.

Berdegué, J. A., & Fuentealba, R. (2011, January). *Latin America: The state of smallholders in agriculture*. Paper presented at the IFAD Conference on New Directions for Smallholder Agriculture (Vol. 24, p. 25).

Ellis, F. (1998). Household strategies and rural livelihood diversification. *Journal of Development Studies, 35*, 1–38.

Cai, F. (2010). Demographic transition, demographic dividend, and Lewis Turning Point in China. *China Economic Journal, 3*(2), 107–119.

Chi, F. (Ed.). (2000). *China's rural land system reform into 21st century*. Beijing: China Economics Press (in Chinese).

Cousins, B., Cousins, T., Hornby, D., Kingwill, R., Royston, L., & Smit, W. (2005). Will formalising property rights reduce poverty in South Africa's 'second economy?' Questioning the mythologies of Hernando de Soto. Plaas Policy Brief, *18*.

Dandekar, H. (1997). Changing migration strategies in Deccan Maherashtra, India, 1885–1990. In J. Gugler (Ed.), *Cities in the developing world: Issues, theory, and policy* (pp. 48–62).

Davis, M. (2006). Planet of slums. *New Perspectives Quarterly, 23*(2), 6–11.

De Soto, H. (2000). *Mystery of capital: Why capitalism triumphs in the West and fails everywhere else*. New York: Basic books.

Dong, S. (2008). *The optimization path of reformation in rural land of China*. Beijing: Social Sciences Academic Press (In Chinese).

Domeher, D., & Abdulai, R. (2012). Access to credit in the developing world: Does land registration matter? *Third World Quarterly, 33*(1), 161–175.

Gilbert, A. (2002). On the mystery of capital and the myths of Hernando de Soto: What difference does legal title make? *International Development Planning Review, 24*(1), 1–19.

Glauben, T., Herzfeld, T., Rozelle, S., & Wang, X. (2012). Persistent poverty in rural China: Where, why, and how to escape? *World Development, 40*(4), 784–795.

Jellinek, L. (1997). Displaced by modernity: The saga of a Jakarta street-traders family from the 1940s to the 1990s. In J. Gugler (Ed.), *Cities in the developing world: Issues, theory, and policy* (pp. 139–155). New York: Oxford University Press.

Johnston, B. F., & Mellor, J. W. (1961). The role of agriculture in economic development. *The American Economic Review, 51*(4), 566–593.

Holstein, J. A., & Gubrium, J. F. (1995). *The active interview*. Thousand Oaks, CA: Sage.

Huang, P., & Peng, Y. (2007). The confluence of three historical trends and the prospects for small-scale agriculture in China. *Social Sciences in China, 4*, 006 (in Chinese).

Lewis, W. A. (1954). Economic development with unlimited supplies of labor. *The Manchester School, 22*, 139–191.

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

Liu, Y. S., Fang, F., & Li, Y. H. (2014). Key issues of land use in China and implications for policy making. *Land Use Policy, 40*, 6–12.

Liu, L., & Han, X. (2006). Recommendations, issues and current status of the game between public and private rights of rural land Institutions. *Jing Ji Zong Heng, 9*, 10–12 (in Chinese).

Nurkse, R. (1961). *Problems of capital formation in underdeveloped countries*. New York: Oxford University Press.

Palomar, J. (2002). Land tenure security as a market stimulator in China. *Duke Journal of Comparative and International Law, 12*, 7–74.

Payne, G., Durand-Lasserve, A., & Rakodi, C. (2009). The limits of land titling and home ownership. *Environment and Urbanization, 21*(2), 443–462.

Ray, D. (1998). *Development economics*. Princeton, NJ: Princeton University Press.
Sjaastad, E., & Cousins, B. (2009). Formalisation of land rights in the South: An overview. *Land Use Policy, 26*(1), 1–9.
Tan, S., Heerink, N., Kuyvenhoven, A., & Qu, F. (2010). Impact of land fragmentation on rice producers' technical efficiency in South-East China. *NJAS-Wageningen Journal of Life Sciences, 57*, 117–123.
Tian, Q., Brown, D. G., Zheng, L., Qi, S., Liu, Y., & Jiang, L. (2015). The role of cross-scale social and environmental contexts in household-level land-use decisions, Poyang Lake Region. *Annals of the Association of American Geographers, 105*(6), 1240–1259.
Tian, Q., Guo, L., & Zheng, L. (2016). Urbanization and rural livelihoods: A case study from Jiangxi province, China. *Journal of Rural Studies*.
Tian, Q., & Lemos, M. (in review). Rural vulnerability to climatic hazards in the context of urbanization: Evidence from China. *World Development*.
Veeck, G., & Pannell, C. W. (1989). Rural economic restructuring and farm household income in Jiangsu, People's Republic of China. *Annals of the Association of American Geographers, 79*(2), 275–292.
Wei, Z. (1989). Discussion on agricultural land privatization under state management. *Chinese Rural Economics, 5*, 15–22 (in Chinese).
Wong, K., Fu, D., Li, C. Y., & Song, H. X. (2007). Rural migrant workers in urban China: Living a marginalised life. *International Journal of Social Welfare, 16*(1), 32–40.
Yao, Y., & Zhang, K. (2010). Has China passed the Lewis turning point? A structural estimation based on provincial data. *China Economic Journal, 3*(2), 155–162.
Yin, P. (2008). *Study of China rural poverty under social exclusion*. Beijing, China: Knowledge Rights Publishing House (in Chinese).
Zhang, H. (2002). China's rural land distributions and transfer of land use rights: Some comments. *Guan Li Shi Jie, 5*, 76–87 (in Chinese).
Zhang, X., & Chen, L. (2005). *Economic development at the village level*. Wuhan, China: Wuhan University Press (in Chinese).
Zhang, X., Yang, J., & Wang, S. (2011). China has reached the Lewis turning point. *China Economic Review, 22*(4), 542–554.

Chapter 5
Exploring Future Rural Development in the Poyang Lake Region

Abstract An agent-based computer model is developed to explore the effects of different subsidy policies and resilience of rural development in the PLR. The model represents land-use and livelihood decision making of farmer households in three types of villages that have poor, average, and rich farmland. Household agents allocate their labor between nonfarm and agricultural work, and make rice cropping choices. They also exchange farmland in a land rental market. Three policy scenarios are examined: subsidies to rice growers, subsidies to large farms, and subsidies to households that rent out their farmland for the long term. The model experiments are not intended to make quantitative predictions but to aid our understanding about (1) the nature and potential effects of these policies across different villages at different stages of development, and (2) how rural development may be affected by economic and environmental shocks. I discuss how policy may need to differentiate across locations and adapt in the near future to effectively promote rural development amid social and environmental changes.

Keywords Subsidy policy • Rural development • Land rental markets • Agent-based modeling • Economic and environmental shocks • Resilience

5.1 Modeling Future Rural Development

5.1.1 Shaping the Future: Three Different Subsidy Policies

Recent agricultural policies in China target farmer households to improve agriculture and rural income. These include cash subsidies to grain producing households, in effect since 2004, and subsidies to households that manage large farms, introduced more recently. In this study I propose another subsidy to households that subcontract their farmland to other households for 20 years under a formal contract. Formulated from the empirical analysis of rural livelihoods in Chap. 4, this subsidy is expected to stimulate farmland rental markets, increase the scale of farming

Part of the material from this chapter was published in Agricultural Systems (Tian et al. 2016).

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0_5

operations, and help secure use rights on rental farmland. It could also encourage migrant families that do well in cities to actually settle in cities and exit agriculture to facilitate other rural households specializing in agriculture. An agent-based model is developed to explore how these three subsidies might influence rural income and agriculture in three village types that reflect poor, average, and good farmland conditions, respectively—as nonfarm work wages rise.

5.1.2 Plausible Economic and Environmental Shocks and Resilience of Rural Development

Future rural development can be affected by social and environmental change. Severe floods cause the major environmental shocks in the Poyang Lake area. A straightforward method for calculating the impacts of a worst-case flood scenario will be provided later in this chapter.

Social shocks, especially those associated with economic crisis or technological innovation in the industrial sector, can produce long-lasting and complex impacts on rural development. When the industrial sector experiences a crisis and slows, migrant workers are usually the first to lose their jobs. They can also be displaced when innovative technologies make the repetitive manual labor that is their niche obsolete. (According to a report by Bloomberg Businessweek on June 11 [2016], the impact of technology has already been observed in Dongguan, a highly developed rural industrial area in Guangdong.)

Economic crises or dramatic technological innovations essentially reduce the chances for migrant workers to find nonfarm work. The return of many migrant workers to the countryside can then produce rippling effects through interactions in the land rental market. It is difficult to calculate the effects of these changes directly; I use model experiments to explore how villages with poor, average, and good farmland resources might respond differently to economic shocks of varying severity.

5.2 Model Conceptualization: Entities, Interactions, and Feedbacks

The agent-based model simulates a village and represents typical village households whose members engage in some combination of migratory work and rice cultivation (Fig. 5.1). In other words, farmer households are agents in the model; each household agent makes individual decisions about how much labor it will spend in agricultural work and how much in migratory work. Household agents also allocate farmland for growing one-season and two-season rice. They exchange farmland in a land rental market and sometimes exchange information, such as land rental prices. They carry out their livelihoods to different degrees of success, mostly determined by the availability of labor, capacity for agricultural and migratory

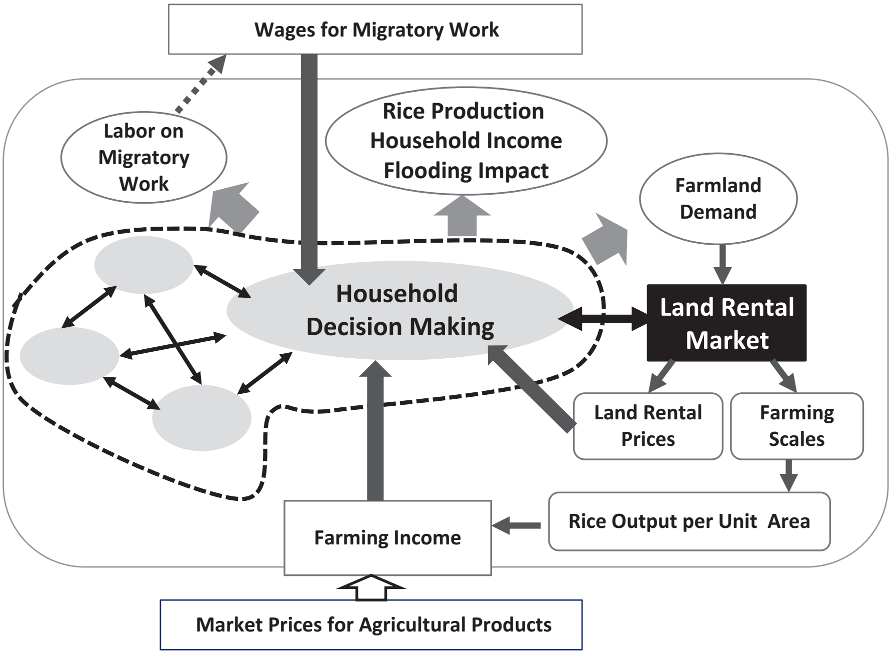


Fig. 5.1 Modeled system: Boundary, agents, interactions, and feedback (adapted from Tian et al. 2016)

work, and farmland endowments. Note that throughout this chapter, I use the term "household agents" when I refer to simulated households in the model.

Wages for migratory work and prices for rice are important factors affecting household decisions. They are treated as exogenous because an individual village that the model simulates have relatively little influence on average wages or prices. Two kinds of feedback between individual decisions and the global state of the system are modeled. The first is that the decisions of household agents collectively determine total farmland demand in a village, which then affects land rental prices and subsequent decision making of household agents. The second is that the total farmland demand affects the farmland area each household agent can obtain, which then influences agricultural productivity and, ultimately, the decisions of household agents.

The model has several major assumptions. First, farmers in the model can always find migratory work at some wage if they want to work in cities. Second, household agents do not hire labor. Third, rice yields increase as the area of farmland a household agent manages increases. Fourth, input use of household agents is not affected by subsidies. Fifth, current grain subsidies are given based on actual planted areas with rice. Sixth, all farmland rental contracts involve payments. Among these assumptions, that household agents do not hire labor in the model is a deliberate choice. I discuss the rationale behind it, and how this assumption may affect model outcomes in the section on model limitations.

The assumption that farmers in the model can always find migratory work at some wage is justified by the fact that most young and middle-aged villagers are doing migratory work, and by calibrating a household migratory work efficiency function (described in Sect. 5.4.3). The assumption that rice yields increase as the farm size increases can be largely justified by the specific context in which farmland is currently highly fragmented and the scale of farming is very small. As we observed in the field, when households manage large farmland, they usually put more effort into management, improve irrigation systems, and invest in machinery and other innovations. A yield function for one- and two-season rice is calibrated separately to reflect yield increase as a result of these efforts and activities (described in Sect. 5.4.4).

Farmers do not seem to increase the use of fertilizers or pesticides because of grain subsidies, based on the interviews and field observations in the villages. Rice cultivation practices, including the types and amounts of fertilizers and pesticides used, are similar among households and across villages. A main difference is that farmers in farmland-rich villages put in more effort in agriculture than those in the other villages, but this is because they have larger, more fertile farmland, and rice cultivation generates larger returns. After all, the current grain subsidy is small, especially relative to nonfarm income, and probably does not provide sufficient incentive for farmers to increase input use.

Land rental relationships often take place between relatives and do not involve payments (Gao et al. 2012; Ma et al. 2015). There are also variations in the implementation of the grain subsidy policy; in some areas, subsidies are given based on historical grain production or contracted land areas instead of actual planted areas (Heerink et al. 2006; Gale 2013; Huang et al. 2013; Yi et al. 2015). Additional experiments are conducted, to test how contracts between relatives, and grain subsidies based on contracted land areas, may affect model outcomes. The experiment results are reported in Sect. 5.8 on robustness analysis.

5.3 Empirical Data Used in the Model

Empirical data obtained from surveys, interviews, and field observations in three villages are compiled and used to represent three types of villages: with poor (V1), average (V2), and rich (V3) farmland (Table 5.1). The purpose is not to use these data to fit the model or simulate these villages in detail, but to explore policy effects in different types of villages with respect to the biophysical environment.

The empirical data are also used for model validation purposes. I compare observed values of several outcome variables at the village level with model outputs, to test the model's ability to generate differences between villages of differing farmland endowments. The important facts that guide the model validation are: (1) in V1 and V2, there is a reduction in two-season rice, with households currently emphasizing one-season rice; in V3, there is no obvious change, and two-season rice still dominates; (2) the average land rental price compares as follows: V1 < V2 < V3; (3) the proportion of income from migratory work compares as follows: V1 > V2 > V3;

Table 5.1 General characteristics of three representative villages selected for use in setting model parameter values, calibrating rice-yield functions and comparing system-level outcomes in villages with different farmland endowments

Characteristics		V1	V2	V3
Natural environment and farmland		Remote and isolated. Plots are hilly and highly fragmented. Farmland is scarce	Plots are flat. About average in fragmentation and total farmland area	Plots are flat, least fragmented. Farmland is relatively abundant
Data relevant to rice yields	Soil fertility	Poor	Good	Good
	Efforts in crop cultivation	Poor	Average	Good
	Collective irrigation system condition	No longer functioning. Small pumps are used to get water from a pond to the fields, and can be rented with an hourly fee	Similar to V1	Well functioning and maintained with the help from the government
Data used for setting model parameters	Farmland area per household	3 mu	7 mu	13 mu
	Average yield of one-season rice (kg per mu)	350	450	500
	Average yield of two-season rice (kg per mu)	500	600	800
Data relevant to model validation	Land rental price (YUAN per mu)	About 50 (Small plots on hills are free)	Between 100 and 150	About 300
	Pct. nonfarm 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 observed, mostly small plots on hills)	100% (no fallowed plots observed)	100% (no fallowed plots observed)
	Land-use change	In the past, two-season rice was widely cultivated	In the past, two-season rice was widely cultivated	No major changes

Note: 1 mu is about 0.067 ha. The rice yields used for setting model parameters in V1 and V2 are not strictly from the surveys. For a description on how these numbers are derived, please see Appendix: Table 5.1

and (4) a small portion of farmland is left fallow in V1, while farmland is mostly cultivated in V2 and V3.

Additionally, the three villages represent different situations that are associated with different rice yields. These differences are used to calibrate the rice-yield functions with increasing scales of farming operations. Further details on the use of empirical data for model validation and yield calibration can be found in the supplement materials (Appendix: Tables 5.1 and 5.2).

5.4 Model Design and Implementation

In this section, I briefly describe some major components of the model. Further details on the implementation of these components can be found in Tian et al. (2016). Some components in this basic model are modified for the policy scenario of subsidizing large farms, which I describe in Sect. 5.6.1. New components are also implemented in the model to represent economic shocks and explore the resilience of rural development, which are addressed in Sect. 5.7.2.

5.4.1 Agents: Farmer Households

Farmer household agents have initial endowments of wealth, labor, and farmland. They differ in their abilities with respect to migratory and agricultural work, social interaction, and cognition (Table 5.2). They know the costs and labor needed per unit area for rice cultivation, and the market price for rice. Each year they try to increase household income based on their past performance in migratory work and rice cultivation, as well as their experience with the land rental market. Details on the representation and implementation of household decision making can be found in the supplement materials (Appendix: Table 5.3).

5.4.2 Land Rental Market

The land rental market is implemented as a two-round exchange process. When the subsidy for a long-term contract is not an option, a household agent wanting to “sublease” more farmland for itself begins the process. It visits a number of randomly chosen household agents, with the number specified by the model parameter *NumHouseholdTrade* (described in Table 5.3). If a targeted household agent does not have a good social relationship with the household agent seeking to sublease the land—and this chance is determined by the social capability of the initiating household agent—no contract is made. If the offered price is greater than asking price, the deal is done at the price offered. If the difference between the two prices is within

Table 5.2 Endowments and attributes of household agents: description and range

Endowment/attribute	Description	Distribution among households	Lower bound	Upper bound
Initial wealth	An initial endowment of wealth (in YUAN)	Uniform	5000	20,000
Labor amount	An endowment of labor (in persons)	Normal (3.6, 1.4)	1.0	7.0
Farmland area	Initially contracted farmland (in mu)	First assigned proportional to labor amount, and then adjusted to reflect demographic changes (described in detail in the section of model initialization)		
Migratory work capability	A unitless multiplier on the average wage for migratory work set by model parameter *AvgWageInitial* (in YUAN per workday). For instance, if a household has a migratory work capability of 0.8, its first member sent to do migratory work gets paid at 0.8**AvgWageInitial* per workday. Migratory work capability of subsequent household members is modeled by a migratory work efficiency function (Fig. 5.2)	Normal (1.0, 0.2)	0.5	1.5
Agricultural work capability	A unitless multiplier on the average yields in a village set by two model parameters *AvgAgriOutput1sRiceInitial* for one-season rice and *AvgAgriOutput2sRiceInitial* for two-season rice	Normal (1.0, 0.1)	0.5	1.5
Social capability	Percentage of households with whom a given household has good relations, affecting the probability of success in negotiating land rental contracts. For instance, a social capability of 0.8 means a household having good relations with 80% of the households in the village, and it will fail in negotiating 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. Model parameters are described in detail in Table 5.3

one-tenth of the farming income estimated by the household agent that wants to sublet, the deal is done at the average of the two prices. After the first round of exchange, if some household agents that wish to rent out their land still have farmland available for rent, they each randomly choose several other household agents with whom to negotiate rental contracts.

When the subsidy for long-term rental contracts is available, a household agent that hopes to sublease farmland to other agents for the long term begins the process first. This household agent visits five more households than it would visit for a single-year contract. If its asking price is lower than the offered price, the deal is done at the price asked. Otherwise, if the asking price is no more than 5% higher than the offered price, the deal is done at the average of the two prices. Then the household agents that intend to subcontract more farmland for themselves through long-term contracts, and whose needs have not been fully met, sample household agents looking to subcontract. After two rounds of exchange through long-term contracts, the household agents update their remaining farmland demands. Those household agents whose needs for long-term rental are not met, and those household agents that have decided to sublease yearly, perform another two rounds of negotiation to make yearly contracts, as described in the previous paragraph.

5.4.3 Migratory Work Efficiency Function

An efficiency function (Fig. 5.2) is used to capture the different levels of labor quality for a household agent's migratory work. This represents field observations that the first members from a household to enter the urban labor market are of the

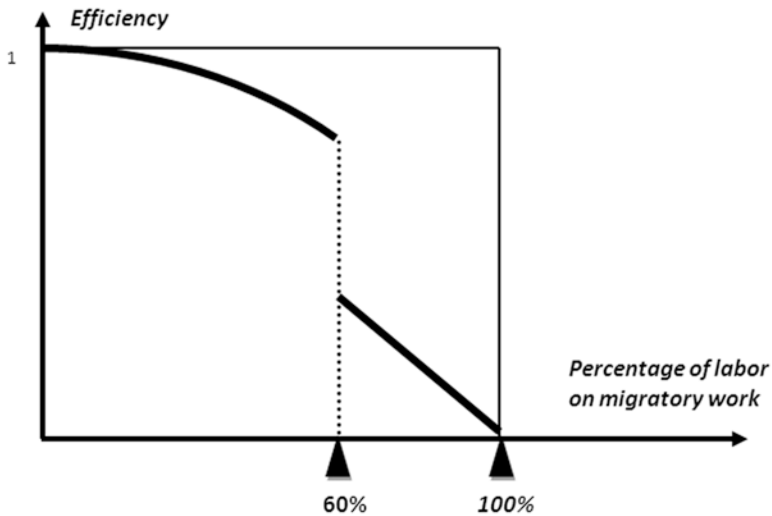
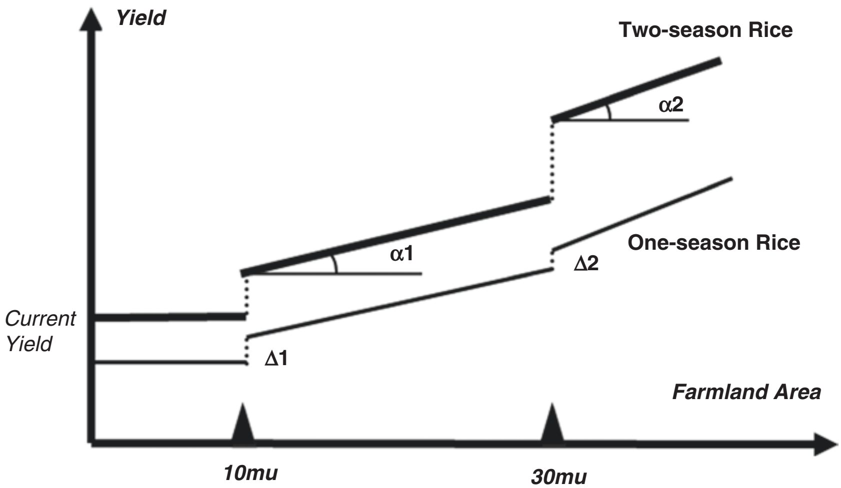


Fig. 5.2 Migratory work efficiency function (Tian et al. 2016)

highest quality (e.g., young men and women with higher skills and/or education). 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).

5.4.4 Rice Yield Functions

Rice yield per unit area is determined by several major factors: fertility of farmland, quality of the irrigation system, management efforts, and machinery usage and other technology. The forms of the rice-yield functions (Fig. 5.3) reflect the effects of changes in effort and capital investments as the area of farmland managed by a household agent increases. Δ1 reflects the increase in yield associated with increased efforts when the area of farmland managed by a household agent reaches 10 mu. Δ2 reflects the increase in yield associated with the improvements in the irrigation system when the area of farmland managed by a household agent reaches 30 mu. Observed yield differences in the three actual villages, which reflect their differences in farmland fertility, irrigation system condition, and management efforts, and other published information, are used to calibrate yield functions for three representative villages in the model.



α1 = α2 = 2.5 for both one-season and two-season rice
Δ1 = 25kg for one-season rice
Δ1 = 50kg for two-season rice
Δ2 = 25kg for one-season rice if the current irrigation condition is NOT good
Δ2 = 150kg for two-season rice if the current irrigation condition is NOT good

Fig. 5.3 Rice yields as a function of the area of farmland managed by a household agent (Tian et al. 2016)

5.4.5 Major Model Parameters and Model Initialization

Several model parameters are designed to facilitate systematic model experiments (Table 5.3). Their default values are used unless specified otherwise in the model experiments. To initialize the model, at the beginning of each model run, 100 household agents are created to reflect approximately the average size of a natural village (i.e., the smallest level of social organization) in the Poyang Lake Region. Each household agent is assigned an initial amount of wealth, labor, farmland area, and capabilities, as described in Table 5.2. Household agents are first assigned an area of farmland that is proportional to household labor amount. This reflects the equality principle used when farmland was first contracted out to individual households in the late 1970s. But since then, there have been demographic changes and farmland areas are no longer equitably distributed. The land areas initially assigned in the model are adjusted by randomly reassigning either one-half, one-third, or one-quarter of the farmland from half of the household agents to other randomly selected households in the village.

5.5 Model Verification and Validation

The model is built on the .NET version of the Repast platform using C# programming language. To ensure appropriate development of the model, a simple structure was implemented first, with more components gradually added. Many extreme cases were also used to test the program. The model was run interactively numerous times to inform the design of systematic experiments and the decisions on how to represent the state of the system.

To enhance the credibility of the model, validations at conceptual, micro, and macro levels have been addressed (Axtell and Epstein 1994; Robinson 1997; Grimm et al. 2005; Brown et al. 2008). The empirical analysis of household surveys and interviews offers important insights into the key elements and the dynamics of the system, and informs the design of the conceptual model. At the micro level, survey data are used to calibrate model parameters and initialize the model when applicable, as just described. At the macro level, three exercises are carried out for formal validation, examining three different processes in the model, as described next. The results from all these model validation efforts suggest that the model captures the dynamics of the actual system reasonably well and are adequate to address the research questions.

The first validation exercise tested the model's ability to reproduce differences among the three surveyed villages in several outcome variables, including average land rental price per unit area, percentage of nonfarm income, percentage of area planted with two-season rice, and percentage of cultivated area. The model

Table 5.3 Model parameters: description and default value

Parameter group	Parameter name	Description	Unit	Default value	Experimental values
Agricultural market	*PriceOfRice*	Rice price on the market	YUAN per kg	2 (current level)	
Industrial sector	*AvgWageInitial*	Average wage for migratory work	YUAN per workday	40 (current level)	0.5: for experiments on land-use change; 40, 60, 80, 100: for policy experiments
Shocks in industrial sector	*ProbFindwork*	Probability that migrant workers find nonfarm work	%	100%	100% to 20%: for resilience experiments
Agricultural sector	*CostCrop1*	Cost associated with fertilizer use and other inputs for one-season rice	YUAN per mu	300	
	CostCrop2	Cost associated with fertilizer use and other inputs for two-season rice	YUAN per mu	600	
Policy-related	*SubsidyCrop1*	Subsidy to one-season rice cultivation	YUAN per mu	50 (current policy)	50–600: for policy experiments
	SubsidyCrop2	Subsidy to two-season rice cultivation	YUAN per mu	100 (current policy)	Double the amount of *SubsidyCrop1*
	SubsidyRenter	Subsidy to long-term renters	YUAN per mu	0	50–600: for policy experiments
	SubsidyBigfarm	Subsidy to large farms	YUAN per mu	0	50–600: for policy experiments

(continued)

Table 5.3 (continued)

Parameter group	Parameter name	Description	Unit	Default value	Experimental values
Household behavior	*AvgNumPlans*	Average number of land-use and livelihood plans households form and evaluate		5	
	NumHouseholdTrade	Number of households a household visits to negotiate land rental contracts		6	
	SocialEffects	Whether social relations affect the success of land-use-right rental deals (when set false, this social effect is ignored)		True	
Village-specific	*AverageArea*	Average area of farmland per household	1: Good	Village-specific parameters are set as described in Table 5.1 for three villages respectively	
	Irrigation System	Condition of the collective irrigation system	0: Poor		
	AvgAgriOutput1sRiceInitial	Average yield of one-season rice	kg per mu		
	AvgAgriOutput2sRiceInitial	Average yield of two-season rice	kg per mu		

experiments successfully generated those patterns in V1, V2, and V3, as described in Sect. 5.3 on empirical data. The second validation exercise tested the model's ability to re-create historical land-use changes in the three surveyed villages. Comparing two scenarios in which nonfarm work is widely available and is limited, the model reproduced the conversion of two-season rice to one-season rice in V1 and V2, and no changes in V3. The third exercise tested the behavior of the modeled land rental market. Model experiments were conducted to examine how modeled land rental prices respond to changes in total farmland area, yield of two-season rice, and migratory work wage. And the results show that the modeled market functions as the microeconomic theory would suggest (see Varian 2002). Further details on validation experiments and results can be found in Tian et al. (2016).

5.6 Effects of Subsidy Policies at Different Stages of Development

5.6.1 Model Experiments for Exploring the Effects of Policies

The model looks at three policy scenarios: subsidies to rice growers, subsidies to large farms, and a proposed subsidy to households that subcontract their farmland to other households for 20 years. To explore the effects of these subsidies, the model is run for each type, ranging from 50 YUAN per mu to 600 YUAN per mu, with an increment of 25 YUAN per mu, under four levels of migratory work wages: 40 YUAN per workday, 60 YUAN per workday, 80 YUAN per workday, and 100 YUAN per workday. Currently, the average wage is 40 YUAN per workday, based on the survey data. The other scenarios represent 50%, 100%, and 150% increases in wages, which are plausible in the near future. Under the current grain-subsidy policy, farmer households receive 50 YUAN per mu for cultivating one-season rice and 100 YUAN per mu for two-season rice. Data on subsidies to large farms are not available from the survey.

Policy effects are examined in terms of changes in average household income, total rice production, and percentage of farming income that indicates potential flood impacts. The total costs associated with each subsidy policy are also considered and compared. Two additional state variables are used to examine farmland concentration and utilization: percentage of farmland managed by the top ten household agents and percentage of farmland planted with rice.

For each village, the model is run 200 times for each scenario of wage, subsidy type, and subsidy amount. Each model run includes 40 time steps divided into two 20-step periods. The first 20-step period serves as the baseline for measuring the effects of a policy implemented in the second 20-step period. At the end of the first 20 steps, the simulated system typically settles into a quasi-equilibrium, following adjustments of household agents' decisions and activities in the land rental market.

The values of all the state variables are recorded at each time step, and in the second period, the total cost (subsidy amount) is also recorded. The values of each of the state variables over the last five steps in each 20-step period are averaged for each model run. These represent the state of the system before and after the implementation of a subsidy policy and are compared to measure the effects of the policy. The variations of these state variables between model runs are also examined, and they are reasonably small (Appendix: Tables 5.4, 5.5 and 5.6).

Land rental contracts of large farms usually are not negotiated between individual households; they are often arranged at meetings that involve discussions of all farmer households in a village. It is difficult to simulate this process in the model, and a simulation is not necessary because it is the outcome—all the farmland in a village is rented out to one or very few households—that matters. Households in the village receive a rental fee for their farmland based on areas. The few households that receive use rights for farmland may not be from the same village.

The basic model is modified as follows to estimate household income in a village under the scenario of subsidizing large farms. Household agents do not negotiate in the land rental market. All household agents put their full labor in nonfarm work and become independent of rice cultivation. A household agent's income is determined by its abilities for nonfarm work, according to the migratory work efficiency function. The model therefore becomes a microsimulation. The household income is estimated by averaging the last five steps of the first 20-step period.

Rice production in a village under the scenario of subsidizing large farms is estimated using the following method. Because farmland becomes extremely concentrated under this scenario, rice production in each village is assumed to reach its full potential, i.e., all farmland is used for two-season rice. While this may overestimate rice production, it represents the optimal level of rice production in a village and is useful for examining the effects of other types of subsidies as well. Based on our field observations and a government report on emerging large farms (Jiangxi government 2014), large farms tend to plant two-season rice to make best use of farmland. The yield for two-season rice used for estimating total rice production in V1, V2, and V3, respectively, is 800 kg, 1000 kg, and 1200 kg, and these are estimated based on the biophysical conditions of farmland in the villages.

Total subsidies are estimated by multiplying the subsidy per unit area by the total farmland area of the village. Because the few households that receive use rights for farmland may not be from the same village, total subsidies are not included in total income of a village. This may slightly underestimate farmer income resulting from this policy. The farmland rental fee per unit area is estimated mostly based on the current average economic return from rice cultivation in a village and is slightly adjusted, considering the current rental fee and the potential productivity of farmland in the village. The estimated rental fee in V1, V2, and V3, respectively, is 400 YUAN per mu, 800 YUAN per mu, and 1000 YUAN per mu.

5.6.2 *Future Development in Villages with Poor, Average, and Good Farmland*

The three simulated villages share several patterns of projected development (Figs. 5.4, 5.5, and 5.6). First, as wages for nonfarm work increase, rice production in each village will decrease, and rice cultivation will eventually be discarded in V1 and V2, without any policy intervention. Second, the average household income in each village rises with nonfarm work wages. Third, as wages increase, the proportion of farming income will decrease, thereby reducing flood impacts on rural livelihoods. These results from model experiments are in agreement with the understanding developed from the household analysis.

Surprisingly, rising wages do not naturally lead to farmland consolidation in the simulated villages. In V1, farmland becomes more widely distributed among household agents as wages rise. In V2, farmland first becomes slightly more concentrated as wages rise to 60 YUAN per workday, but then less concentrated as wages further increase. In V3, the degree of farmland concentration is low at the current wage level of 40 YUAN per workday and stays relatively stable at relatively low wage levels. It increases slightly as wages continue to rise, but eventually declines as wages further rise to 100 YUAN per workday. Farmland consolidation does not happen because when wages are sufficiently high, even larger farms in the model cannot generate returns comparable to nonfarm work, and some farmland is consequently left uncultivated (Fig. 5.7).

These different trajectories of the simulated villages in farmland arrangement reflect their relative farmland profitability. Farmland in V1 is marginally productive, and its household agents already rely mostly on nonfarm work at the current wage level. They quickly drop rice cultivation as wages rise, and larger farms in V1 cannot compete with nonfarm work, even at low wage levels. Farmland in V3 is highly productive, and most of its household agents find it more profitable to combine nonfarm work with rice cultivation. This leads to a low degree of farmland concentration and full use of farmland. Farmland concentration in V3 remains low until wages rise to very high levels.

Farmland productivity in V2 is at an intermediate level, and the household agents respond to rising wages in a more complex way. As wages rise, at first most of the household agents find it more profitable to do more nonfarm work, with some household agents finding it more profitable to manage larger farms. This results in greater farmland concentration and near full use of farmland. But as wages further rise, those household agents that manage larger farms begin to find it more profitable to do nonfarm work, resulting in a proportion of farmland in the village left uncultivated. This suggests that at some wage levels, farmland in villages with average farmland resources could become more concentrated and fully utilized, which, however, may not be a stable arrangement.

This result is relevant to agricultural development in some other Asian countries that have the same issues of small farm sizes. Farms are expected to become

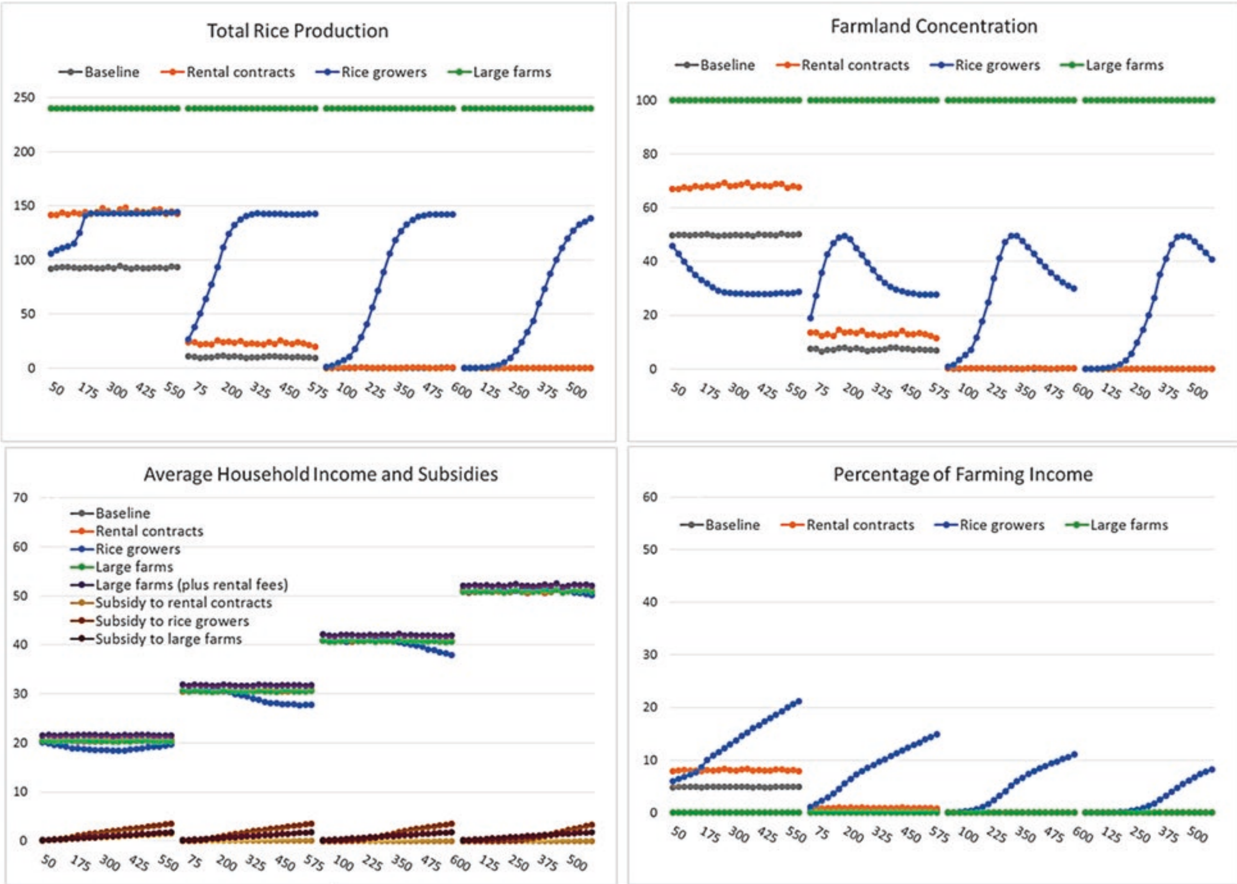


Fig. 5.4 Effects of different subsidies in V1 with poor farmland resources (see Appendix: Table 5.4 for data). The degree of farmland concentration is represented by the percentage of farmland managed by the top ten households in a village. The horizontal axis represents subsidy amount in YUAN per mu. The four groups of diagrams from left to right represent wages at 40, 60, 80, and 100 YUAN per workday. The unit is 1000 kg for total rice production, and 1000 YUAN for average household income and subsidies

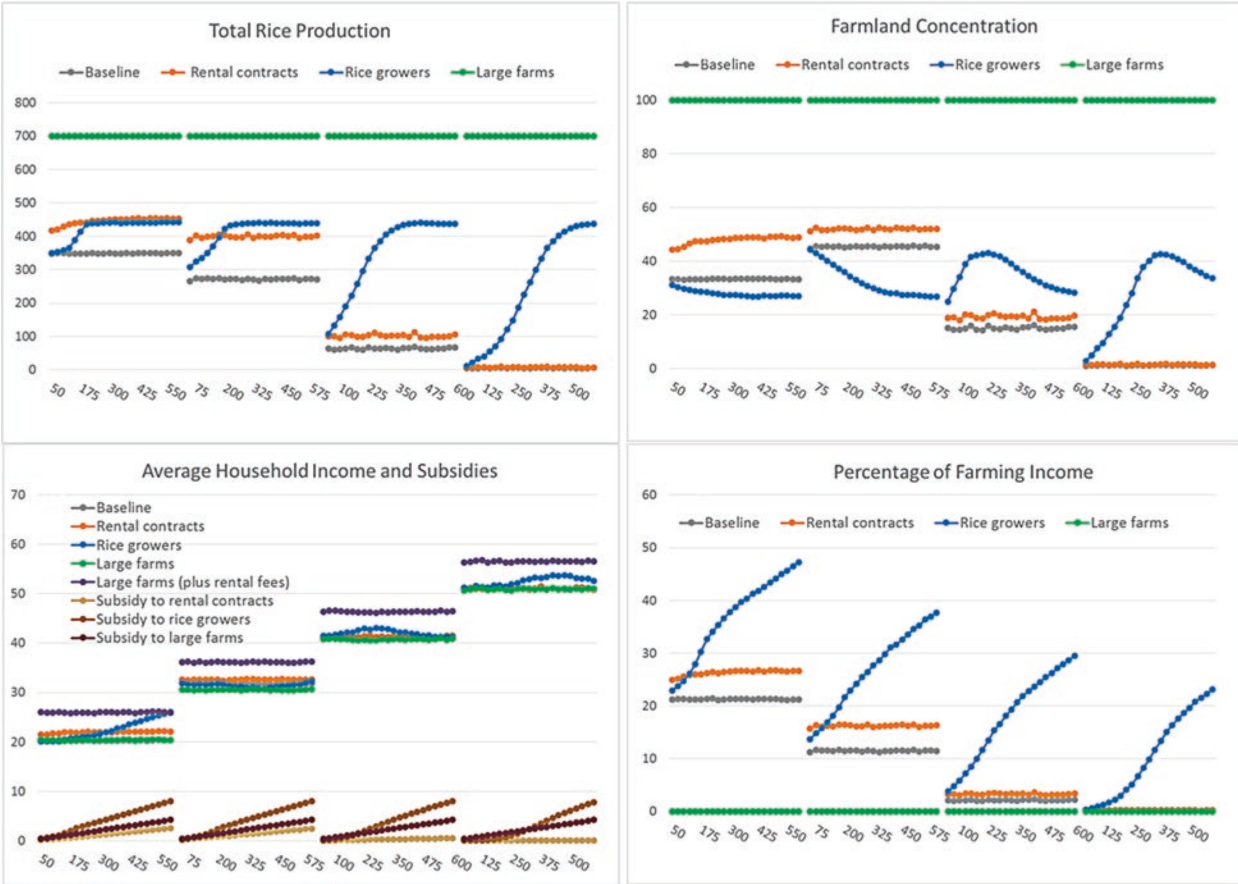


Fig. 5.5 Effects of different subsidies in V2 with average farmland resources (see Appendix: Table 5.5 for data). The degree of farmland concentration is represented by the percentage of farmland managed by the top ten households in a village. The horizontal axis represents subsidy amount in YUAN per mu. The four groups of diagrams from left to right represent wages at 40, 60, 80, and 100 YUAN per workday. The unit is 1000 kg for total rice production, and 1000 YUAN for average household income and subsidies

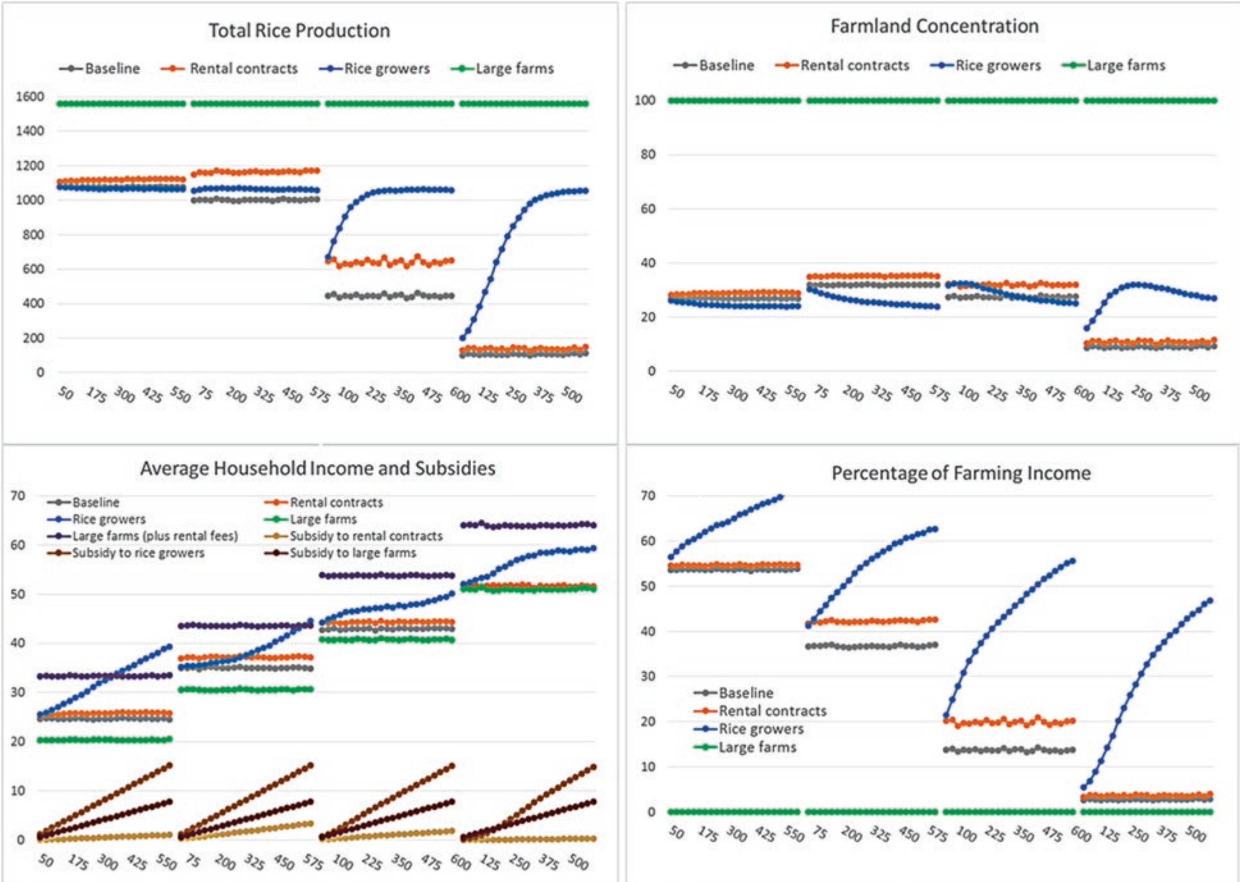


Fig. 5.6 Effects of different subsidies in V3 with rich farmland resources (see Appendix: Table 5.6 for data). The degree of farmland concentration is represented by the percentage of farmland managed by the top ten households in a village. The horizontal axis represents subsidy amount in YUAN per mu. The four groups of diagrams from left to right represent wages at 40, 60, 80, and 100 YUAN per workday. The unit is 1000 kg for total rice production, and 1000 YUAN for average household income and subsidies

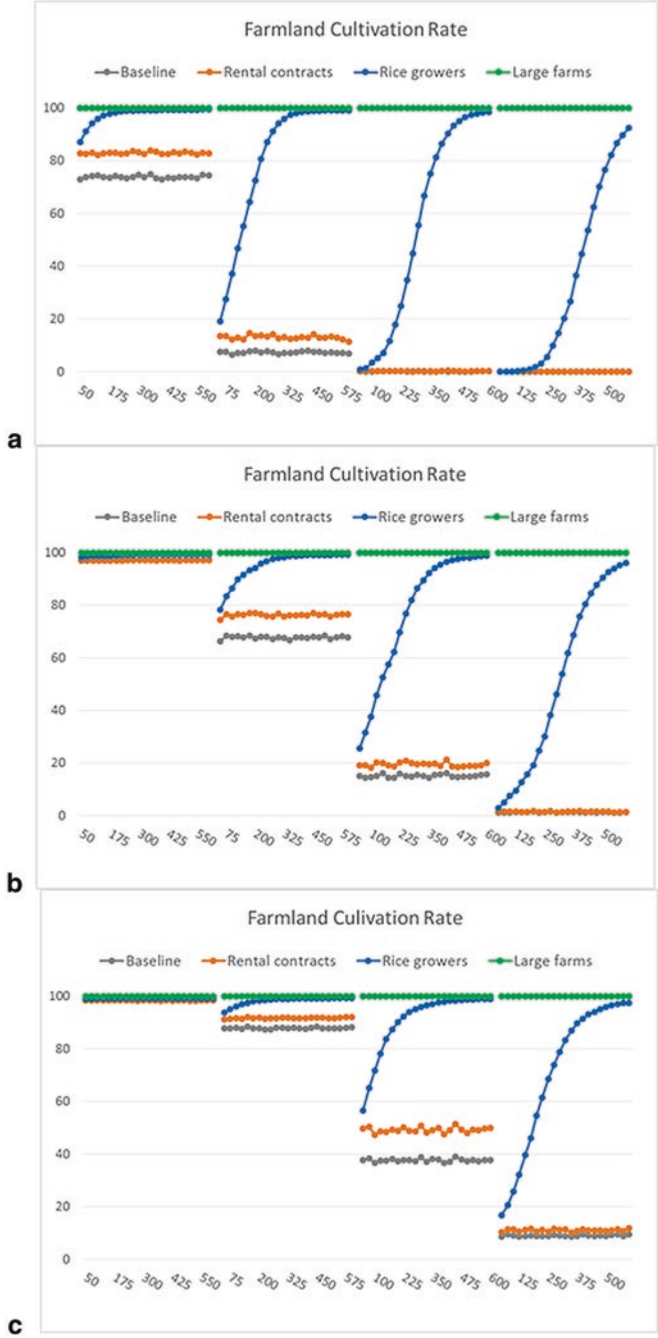


Fig. 5.7 Farmland utilization rates in three simulated villages as wages for nonfarm work increase from 40 to 60, 80 and 100 YUAN per workday. (**a**) V1, (**b**) V2, and (**c**) V3. The horizontal axis represents subsidy amount in YUAN per mu. Data associated with these figures can be found in supplement materials (see Appendix: Tables 5.4, 5.5, and 5.6)

progressively larger, as per capita income rises and migrant workers leave agriculture (Hazell and Rahman 2014). However, a decrease in farm size has been observed in some Asian countries, such as Thailand, the Philippines, and Indonesia, where massive socioeconomic transformations have occurred (FAO 1990, 2000, 2010). The small farm size may render Asia as a whole losing comparative advantages in agriculture in the world markets (Otsuka 2013; Otsuka et al. 2014).

The empirical household analysis in Chap. 4 shows that a range of factors can limit farm sizes in China. These model experiments expand our understanding by demonstrating the complex micro-level dynamics and macro-level outcomes as wages rise. Policy could play a role to influence the evolution of smallholder farms in the future (see also Rigg et al. 2016).

The differences in future development among the three simulated villages, again, mostly reflect their differences in economic returns from rice cultivation relative to nonfarm work. The farmland productivity decreases from V3 to V2 and V1. As wages rise in the future, economic returns from rice cultivation in V2 and V3 will decrease relative to nonfarm work. Without further policy intervention, what happens in V1 now will likely happen in V2, and what happens in V2 now will likely happen in V3.

5.6.3 Policy Effects in Villages with Poor, Average, and Good Farmland

First, the impacts of all three subsidies on improving income across the simulated villages at all wage levels are small. Of interest, there is a noticeable decrease in average income in V1 as the subsidy to rice growers per unit area increases. This is because increasing the subsidy attracts more labor to rice cultivation and increases the competition for farmland among the household agents as well. Without subsidies to rice growers, the household agents in V1 would spend more labor in nonfarm work and obtain higher incomes. Also, notice that subsidies to rice growers produce a perceptible and relatively larger increase in average income in V3 than the other villages. This is because the household agents in V3 receive large amounts of subsidies, i.e., with high government costs.

Second, the policy effects on improving rice cultivation vary across the simulated villages and at different levels of wages. Rental subsidies are in general most effective at relatively low wage levels, and become less effective, or even ineffective, at high wage levels. In contrast, the increase in rice production resulting from subsidies to rice growers is highly sensitive to the amount of subsidy, with a higher subsidy amount producing more rice.

There appears to be a maximum amount of rice that a village can produce under subsidies to rice growers at each wage level, referred to as "maximum rice amount." This maximum rice amount results from farmland in a village being fully planted with rice. But because farmland is not all planted with two-season rice, it is considerably less than the optimal level of rice production that may be achieved under subsidies to large farms. Subsidies to large farms can potentially optimize rice production in each village with a cost that is comparable to subsidies to the rice growers. The costs associated with rental subsidies are in general the lowest in each village and at all wage levels.

In V1, rental subsidies produce a large increase in rice production at the current wage level of 40 YUAN per workday with very little cost. This is because household agents in V1 find it more profitable to rent out their farmland for long terms, with even a small amount of rental subsidies. But as wages rise to 60 YUAN per workday and higher, even larger farms in V1 cannot produce income comparable to nonfarm work, and rice cultivation is largely abandoned. Consequently, rental subsidies become ineffective at affecting land exchanges.

In V2, rental subsidies also result in a relatively large improvement in rice production at the current wage level with relatively little cost. At the wage level of 60 YUAN per workday, rental subsidies still produce a large effect on rice production in V2. However, subsidies to rice growers begin to outperform rental subsidies when the subsidy to rice growers rises to about 200 YUAN per mu and higher, with higher costs than rental subsidies. As wages rise further to 80 YUAN per workday and higher, rental subsidies become ineffective in V2. Then, it also needs a substantially large amount of subsidies to rice growers to achieve the maximum rice amount in V2.

In V3, both subsidies to rental contracts and rice growers produce no noticeable effects on rice production at the current wage level. This is because most household agents in V3 find it more profitable to combine nonfarm work and rice cultivation. They do not rent out their farmland, and farmland in V3 is fully utilized even without subsidies. At the wage level of 60 YUAN per workday, rental subsidies produce a slightly better, but overall small, effect on improving rice cultivation than do subsidies to rice growers. As wages rise to 80 YUAN per workday, subsidies to rice growers begin to outperform rental subsidies, but with much higher costs. Rental subsidies become ineffective in V3 as wages rise to 100 YUAN per workday, and it needs substantially large amounts of subsidies to rice growers to achieve the maximum rice amount in V3.

Notice that the patterns of policy effects on rice production in V1 at lower wage levels are similar to those in V2 and V3 at higher wage levels. And the differences, again, largely reflect the differences among the villages in farmland profitability relative to nonfarm wages.

Third, subsidies to large farms lead to independence of farmer households from rice cultivation, thereby reducing flood impacts on rural livelihoods, except for the few large-farm holders. Both subsidies to rental contracts and rice growers can potentially increase flood impacts on rural livelihoods when they are effective at increasing rice production. Under policy scenarios of subsidizing rice growers and rental contracts, the proportion of farming income at the village level is mainly determined by wages and farmland productivity in a village.

In V3, the proportion of farming income is generally higher than V1 and V2, and can be quite high when the subsidy to rice growers per unit area is large. But because farmland-rich areas are usually protected by high-quality levees, flood impacts on rural livelihoods and agriculture in villages like V3 are generally low. Rental subsidies slightly increase the dependence of rural livelihoods on agriculture at the current wage level of 40 YUAN per workday in V1, and at 40 YUAN per workday and 60 YUAN per workday in V2. Subsidies to rice growers in general increase dependence of farmer households on rice cultivation more than rental subsidies, and to a larger degree as the subsidy becomes larger. These differences in potential flood impacts resulting from subsidy policies need to be taken into account, particularly in villages like V1, because these villages are usually protected by low-quality levees.

Of note, the subsidy to rice growers produces a nonlinear effect on farming scales at higher wage levels while showing a negative effect on farmland consolidation at lower wage levels. Specifically, the subsidy to rice growers makes farmland more widely distributed among household agents, notably in V1 at the current wage level, and in V2 at the wage level of 60 YUAN per workday. This is because the subsidy to rice growers attracts more labor to rice cultivation at relatively low wage levels. The nonlinear effects on farming scales show at wage levels of 60, 80 and 100 YUAN per workday in V1; at 80 and 100 YUAN per workday in V2; and at 100 YUAN per workday in V3. During these periods, farmland first becomes more concentrated and then more widely distributed as the subsidy to rice growers per unit area increases.

At relatively high wage levels, under the subsidy to rice growers, household agents begin to pick up rice cultivation, and some household agents find it more profitable to manage larger farms. But as the subsidy further increases, most household agents find it profitable to include rice cultivation and decide not to rent out their farmland. Therefore, full utilization of farmland at relatively high wage levels under large subsidies to rice growers is achieved through rice cultivation by many individual household agents. This is not considered in general to be a desirable farmland arrangement because small farms tend to remain inefficient in the long run.

Another interesting pattern is that the subsidy to rental contracts shows a nonlinear effect on rice production in V2 at the current wage level. As the rental subsidy increases, rice production in V2 first increases quickly but then slows down and levels off. This shows that household agents in V2 are sensitive to the size of the subsidy. The nonlinear pattern could be used to choose efficient subsidy size.

5.6.4 Differentiating Policy Interventions across Villages and Adaptive Policy

What do these modeling results mean for policy interventions in the Poyang Lake region? As demonstrated, future rural development and policy effects are likely to be different in different types of villages and at different stages of development. This suggests that differentiating policy interventions across villages is likely to produce better outcomes than will uniform policy interventions, and that adapting policy will be necessary.

The variations in future development and potential policy effects across the three types of villages largely reflect their differences in farmland profitability. As wages for nonfarm work rise, relative economic returns from rice cultivation in V2 and V3 will decrease, making their situations similar to the current situation in V1. And this will happen sooner in V2 than in V3. Therefore, differentiating policy interventions across the three villages is essentially not that different from adapting policy interventions at different stages of development.

First of all, farming can increase rural income to a limited degree, due to limited farmland and large rural populations. Urbanization will likely continue to play an important role in absorbing rural labor. As discussed in Chap. 4, it is important that policy considers the quantity and diversity of rural populations to guide urbanization to the benefit of rural households. Development, migration, and land policies need to synergistically foster healthy rural-urban development dynamics and promote simultaneous growth of the agricultural and industrial sectors so that rural households can build robust livelihoods via different paths.

Second, it will become increasingly challenging to maintain grain production as nonfarm income continues to rise, and some forms of subsidies will likely be necessary to promote agriculture. A decline of agriculture has also been observed in some other rural areas, especially in those areas with relatively high industrial development (Liu et al. 2005; Deng et al. 2006; Lichtenberg and Ding 2008; Seto et al. 2011). Besides rice production and costs, flood impacts should be taken into account when making policy choices in the PLR, especially for places with high flood risks.

Subsidies to large farms could produce best outcomes with regard to rice production. However, when many households in a village still rely on farming to some extent, subsidizing large farms may not be effective and could increase inequality. Also, it would be more beneficial to all rural households if the degree of farmland concentration is in accord with the amount of rural labor employed in the urban sector. Farmland utilization can provide some clue as to when the timing may be right to implement this policy in different types of villages.

Based on the model experiments, farmland cultivation rate drops below 25% when wages rise to 60 YUAN per workday in V1, 80 YUAN per workday in V2, and 100 YUAN per workday in V3. We may expect that the subsidy to large farms is likely to start taking effect first in villages with poor farmland, then in villages with average farmland, and finally in villages with rich farmland. However, the poor farmland in V1 is not attractive to rice growers unless it is changed to other uses, and the increase in rice production in V1 would be affected by flooding. Another new study with my colleagues at Jiangxi Normal University, Professor Lin Zheng and Dr. Shuhua Qi, shows that the large farms that emerged in the past few years in Jiangxi Province are mostly in areas with soils favorable for rice growing.

Subsidies to large farms may be more effective for villages with average farmland resources. Farmland in V2 is suitable for rice growing but is not fully planted with two-season rice, as in V3, for two reasons. First, the farmland area per household is smaller in V2 than in V3. Second, the collective irrigation system has stopped working in V2, whereas the irrigation system in V3 is well maintained and functioning with assistance from the township government. If farmland in V2 is consolidated, it will be worth investing in irrigation systems, which will help realize farmland's full potential.

Demographic changes can affect the effectiveness of subsidies to large farms. As their children are attending college and settling in cities, middle-aged farmers begin to see that rice cultivation, which costs labor and involves hard work, is no longer essential for their livelihoods. If they are given a rental fee comparable to what their farmland can produce, many of them are willing to consider giving up farming. Based on conversations with college students at Jiangxi Normal University who are from different villages in the PLR, this happened in some villages where farmer households collectively decided to rent out their farmland. Therefore, the policy of subsidizing large farms can start taking effect now in some villages, though it will probably become more widely effective as nonfarm wages rise.

The proposed rental subsidy policy, with the least costs, could be an appropriate choice for villages with poor or average farmland resources when nonfarm wages are relatively low. In villages like V2 with average farmland, household decisions are sensitive to the amount of rental subsidies. Subsidizing households that subcontract their farmland to others for long terms could effectively stimulate land rental markets, and the subsidy amount could be chosen to achieve highest efficiency. The subsidy amount could also be adjusted as development advances such that the degree of farmland concentration is in accord with the amount of rural labor employed in the industrial sector to facilitate healthy rural-urban dynamics.

In villages with poor farmland like V1, the rental subsidy policy could also address the issue of inequality in natural resources. Because farmland is marginally productive in these villages, land rental prices are relatively low. Farmer households that intend to specialize in agriculture can rent in large areas at relatively low costs. This compensates their poor natural resources to some degree. Additionally, most farmer households in these villages already rely largely on migratory work for their livelihoods. If they receive subsidies for subleasing their farmland to other households under long-term contracts, they will be more willing to sign such contracts; and this also makes it easier for those households that intend to specialize in agriculture to acquire large farmland areas. Once consolidated, the marginal farmland may be used in other ways to increase land profitability and reduce flood impacts. The subsidies the renters receive can help improve their urban livelihoods. Thus, every farmer household can improve its situation. There are a variety of arrangements that can be made with rental subsidies to further address farmland inequality among villages (Tian et al. 2016).

Subsidizing rice growers does not seem to be a good policy choice, considering its economic performance. It appears to have very limited positive effects, even with undesirable outcomes, and would involve substantially large costs to be effective at improving rice production. Particularly in villages with poor farmland it may make farmland more decentralized and lead to a reduction in total income. Households in these villages receive much lower subsidies than those in farmland-rich villages, further increasing inequality in natural resources and levee systems. Its effects are also immediate and lack the potential for continuous growth (Tian et al. 2016).

However, our interviews show that the subsidies to rice growers makes farmer households feel that the government cares about them, and thus have a positive social effect. And farmland-rich villages like V3 produce much more rice than farmland-poor villages like V1. The social effect and the large rice production in farmland-rich villages may justify subsidies to rice growers. The issue of inequality could be mitigated by other policy interventions, such as facilitating and assisting households in farmland-poor villages to develop secure urban-based livelihoods, and through the proposed rental subsidies.

It will probably not be a good idea to increase the amount of subsidies to rice growers to promote agriculture, for two reasons. At lower wage levels, rental subsidies could produce larger positive effects than would subsidies to rice growers, and with much lower costs. At higher wage levels, subsidies to large farms could produce larger positive effects than subsidies to rice growers, with similar costs. Some economists also agree that despite significant increases in agricultural subsidies, these subsidies in general have limited impacts on increasing agricultural outputs, due to influences of nonfarm income (Gale et al. 2005; Heerink et al. 2006; Huang et al. 2011; Gale 2013). Subsidies to rice growers could also produce complex outcomes on farmland arrangements at relatively high wage levels and might have unintended consequences on farmland consolidation.

Third, the insight generated from the model experiments—that rising wages for nonfarm work may not naturally lead to farmland consolidation and, consequently, improved land-use efficiency—can have policy implications. There appears to be a critical period during which rising wages can help farmland consolidation in most villages. But that outcome of increased farmland concentration may not be a stable arrangement, unless luck has it that the critical period coincides with the generational transition. Policy could ride that momentum to push farmland consolidation through. Promoting long-term legal rental contracts would be helpful for stabilizing the farmland arrangement. Migration policy that facilitates farmer households that do well in cities to settle there permanently could also play an important role. Subsidies to households managing large farms could further enlarge scales of farming operations.

5.7 Resilience of Rural Development

5.7.1 Potential Effects of Severe Floods

The impacts of severe floods in the worst scenario can be estimated as follows: Rice production would be totally lost, and the amounts would total 89,170 kg in V1, 344,264 kg in V2, and 1,065,479 kg in V3 (Table 5.4). Income would be reduced, and the reduction of average household income would total 931 YUAN in V1, 4,252 YUAN in V2, and 13,133 YUAN in V3 (Table 5.4). V1 would most likely be affected, due to poor levee protection. However, farming income is only about 5% of income in V1, and rice production in V1 is only about 6% of what is produced in V2 and V3 together. Therefore, the loss in income would not be felt strongly by farmer households in villages like V1, and the reduction in rice output in these villages would not be significant for overall food production in the region. The loss in

Table 5.4 Worst effects caused by severe floods

Village	Loss in total rice production (kg)	Reduction in household income (YUAN)	Percentage of reduction in income (%)	Likelihood
V1	89,170	931	4.92	Very high
V2	344,264	4252	21.29	Low to medium
V3	1,065,479	13,133	53.85	Very low

income could be felt by households in V2 and V3 because about 20% and 50%, respectively, of income is from rice cultivation. However, the negative effects of severe flooding on income would likely be for just one year in all villages. Following a severe flood, more farmers would probably seek nonfarm work in cities, as happened after the massive 1998 flood.

Agriculture could be affected by severe floods longer because farmers might give up rice cultivation in the following years, fearing that floods will recur. Rice production in V3 could be affected the most, but the chance that this worst-case scenario happens in V3 is relatively small. Not only are important agricultural centers in the region protected by high-quality levees, the government also puts significant effort into strengthening these important levees when severe floods occur. Overall, the major impact of severe floods would be a reduction in agricultural production in farmland-rich areas, which could last for more than one year, but with a relatively small chance. In general, rural development is likely to bounce back in relatively short terms.

5.7.2 Modeling Potential Effects of Economic Shocks

A shock with a certain degree of severity, defined by duration and probability of finding nonfarm work, is introduced to the model at the 21st time step, after the simulated system settles into a quasi-equilibrium (Fig. 5.8). The model is run for 200 times under a slight shock, a moderate shock, and a severe shock, respectively, for each type of villages. Each time, the model runs for 20 more steps following the introduction of the shock to explore the effects of the shock. Current subsidies to rice growers and the current wage level of 40 YUAN per day are used in these experiments.

The same state variables for exploring policy effects are recorded for each time step. Additionally, average farmland rental price is recorded because economic shocks most likely create ripping effects through household interactions in the land rental market. The values of all state variables from 200 runs are averaged for each time step to represent typical responses of a village to a shock. Their variations between model runs for each village are also examined and are reasonably small (Appendix: Tables 5.7, 5.8, and 5.9).

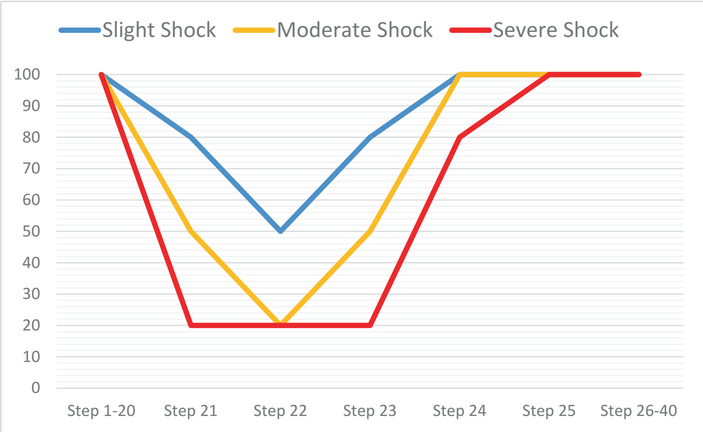


Fig. 5.8 Three scenarios of economic shocks, introduced at the 21st time step in the model, represented by changes in probability of finding nonfarm work following a shock

5.7.3 Rural Development under Economic Shocks

The three simulated villages respond to economic shocks in several similar ways. Following an economic shock, average household incomes drop immediately, and dependence on farming increases simultaneously (Figs. 5.9, 5.10, and 5.11). Other variables representing the state of the agricultural system, i.e., rice production, farmland concentration, and farmland utilization, also change, but their changes are not as dramatic as the change in income. The agricultural system in each simulated village shows a series of adjustments as household agents make adjustments, which cause fluctuations on the land rental market.

The average rental prices rise significantly, but this occurs later than the drop of income, and prices also recover more slowly. The average rental price in each village peaks several time steps after the probability for finding nonfarm work already bounces back to 100%. It takes almost twice as long as the duration of a shock for the average rental price to bounce back to the normal range. Consequently, it takes quite some steps (years) for all aspects of the agricultural system to recover, although the system does eventually recover. Among all aspects of the agricultural system, farmland concentration is relatively quick to respond to shocks, as household agents each begin to cultivate more farmland immediately after a shock kicks in.

There are some notable differences in villages' responses to economic shocks. Income drops and the percentage of farming income increases at much higher rates in V1 than in V2 and V3 under any shocks (Table 5.5; Fig. 5.12). This is expected because household agents in V1 rely heavily on nonfarm work. The significant reduction in income and an increase in dependence on agriculture could render

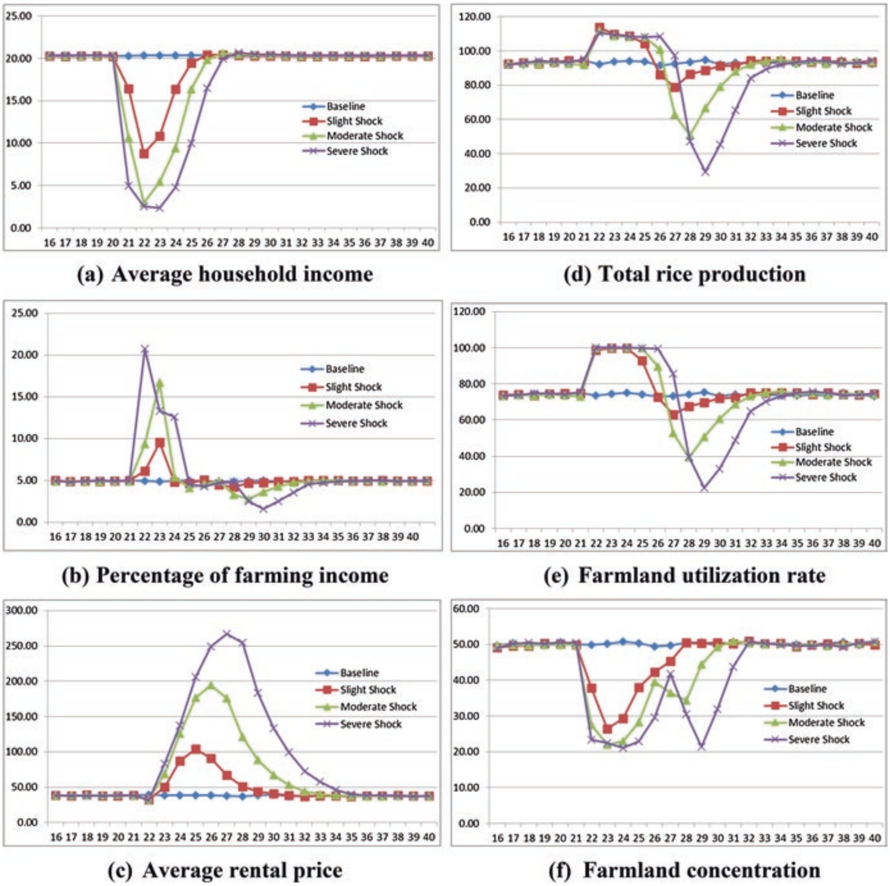


Fig. 5.9 Responses to economic shocks in V1. Data associated with these figures can be found in supplement materials (Appendix: Table 5.7). (**a**) Average household income in 1000 YUAN. (**b**) Percentage of farming income. (**c**) Average rental price in YUAN per mu. (**d**) Total rice production in 1000 kg. (**e**) Farmland utilization rate. (**f**) Farmland concentration

households in V1 helpless if a severe flood happens during the same period. The rates of change in income and percentage of farming in V3 are the smallest among the three villages, also as expected. The amounts of change in V3 are also relatively small and are probably not felt significantly by the village households. These differences suggest a cushioning effect of farmland resources in times of economic difficulty.

How the agricultural system responds to shocks differs in the three simulated villages, depending also on the severity of shocks. The magnitude of adjustments in the agricultural system in V1 overall appears larger than in V2 and V3 (Figs. 5.9, 5.10, and 5.11). The average land rental price in V2, however, increases more significantly under severe shocks than in V1 and V3 (Fig. 5.12; Table 5.5).

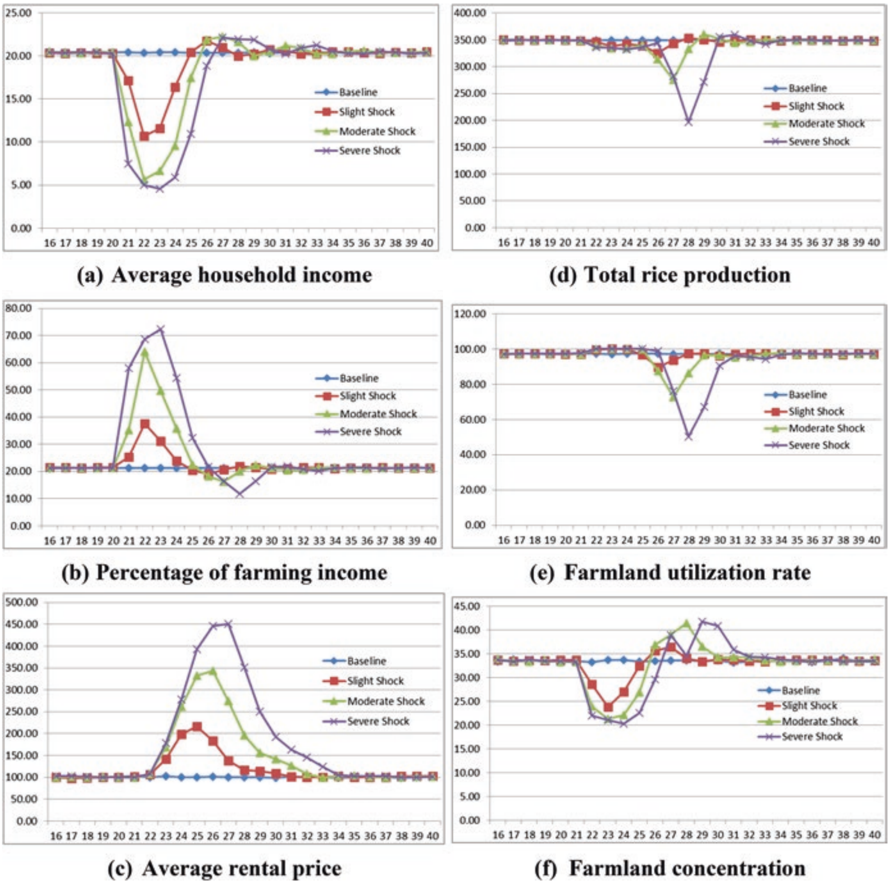


Fig. 5.10 Responses to economic shocks in V2. Data associated with these figures can be found in supplement materials (Appendix: Table 5.8). (**a**) Average household income in 1000 YUAN. (**b**) Percentage of farming income. (**c**) Average rental price in YUAN per mu. (**d**) Total rice production in 1000 kg. (**e**) Farmland utilization rate. (**f**) Farmland concentration

This again reflects the fact that farmland in V2 has an intermediate level of productivity, and the land rental market in V2 is sensitive to external influences.

In general, the degree of farmland concentration decreases and then increases in all villages after a shock starts. Of note, there is a period in which farmland concentration goes beyond the normal range before finally falling back to the normal range in V2 and V3. This is because household agents have no complete, precise information about the future, and their adjustments are trials and errors, causing ripping effects through interactions in the land rental market.

Farmland concentration in V1 bounces back to the normal range under a slight shock; but under more severe shocks, it drops again, following an initial rise, before it finally recovers. This suggests that farmland arrangements in V1 may be relatively

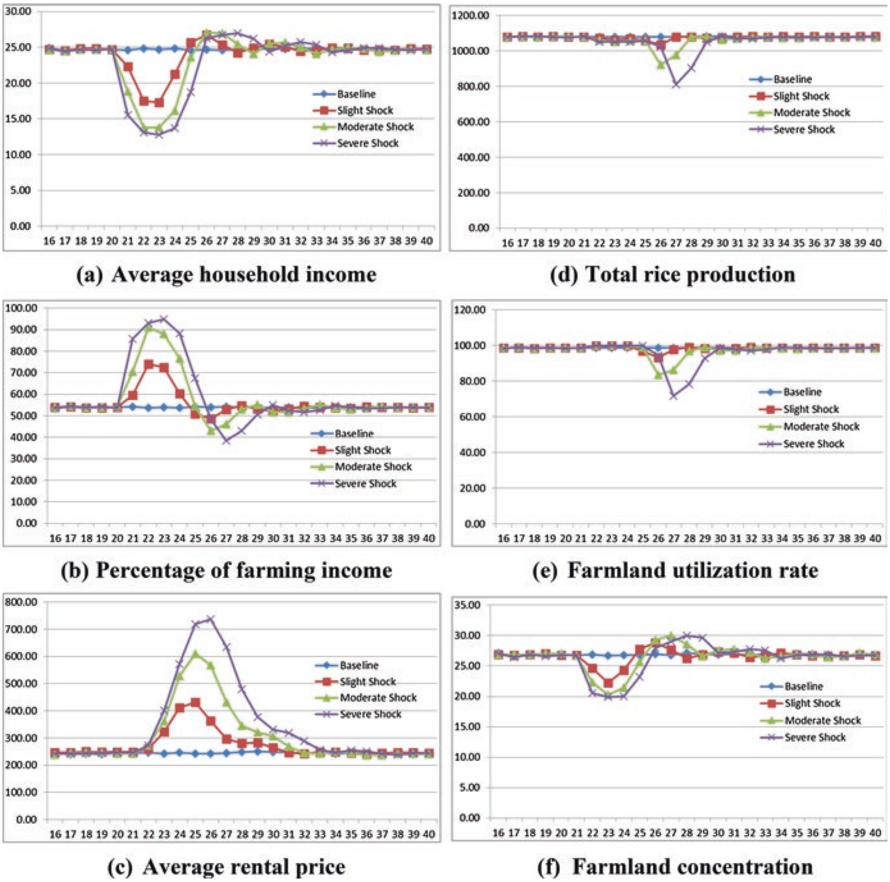


Fig. 5.11 Responses to economic shocks in V3. Data associated with these figures can be found in supplement materials (Appendix: Table 5.9). (**a**) Average household income in 1000 YUAN. (**b**) Percentage of farming income. (**c**) Average rental price in YUAN per mu. (**d**) Average rental price in YUAN per mu. (**e**) Farmland utilization rate. (**f**) Farmland concentration

easy to restore under slight shocks because household agents quickly pick up nonfarm work as the economic situation begins to improve. However, longer durations of severe shocks could make their quick adjustments ineffective, and they might have to go back to farming in the middle of the recovery.

The changes in rice production, which is closely related to the cultivation rate, show different patterns in V1 than in V2 and V3. Rice production in V2 and V3 does not change much immediately following a shock because their farmland is almost fully planted with rice before the shock. But later rice production in V2 and V3 experiences a slight decrease as a consequence of the decline in farmland concentration. Rice production in V1 increases immediately following the shocks because household agents each pick up more rice cultivation. But later rice production in V1 drops significantly as they pick up more nonfarm work again and farmland cultivate rate decreases.

Table 5.5 Potential effects of economic shocks. The time step at which extreme values of the state variables occur following a shock are recorded, as shown in the column Step

State variable	Village	Baseline	Light shock			Moderate shock			Severe shock		
			Extreme value	Change rate	Step	Extreme value	Change rate	Step	Extreme value	Change rate	Step
Average income (1000 YUAN)	V1	20.33	8.77	−56.86	22	2.94	−85.54	22	2.32	−88.59	23
	V2	20.38	10.67	−47.64	22	5.65	−72.28	22	4.54	−77.72	23
	V3	24.71	17.29	−30.03	23	13.75	−44.35	22	12.75	−48.40	23
Percentage farming income (%)	V1	4.92	9.58	94.72	22	16.71	239.63	22	20.72	321.14	21
	V2	21.29	37.57	76.47	22	64.04	200.80	22	72.39	240.02	23
	V3	53.85	74.11	37.62	22	90.94	68.88	22	94.95	76.32	23
Average rental price (YUAN per mu)	V1	37.91	104.47	175.57	25	194.40	412.79	26	166.86	340.15	27
	V2	100.18	216.47	116.08	25	343.28	242.66	26	451.61	350.80	27
	V3	244.17	431.55	76.74	25	610.55	150.05	25	736.89	201.79	26

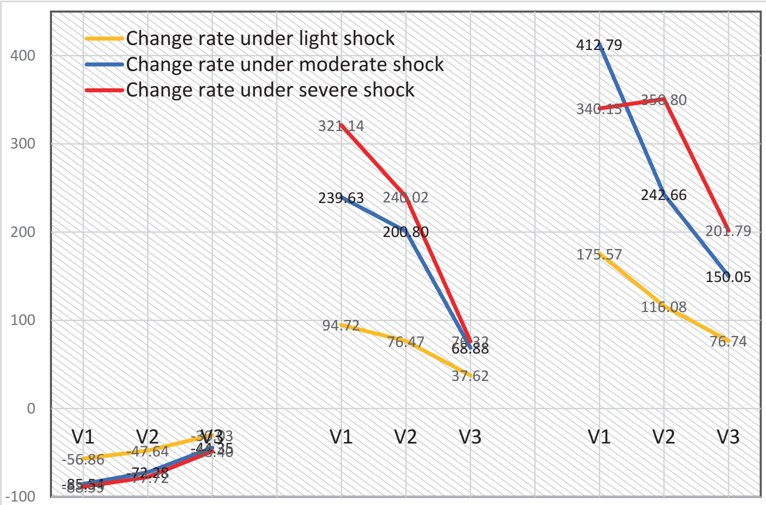


Fig. 5.12 Severity of economic shocks and impacts in three simulated villages. The first group of lines represent average household income, the second group percentage of farming income, and the third group average rental price

5.7.4 Enhancing Resilience amid Social and Environmental Changes

The policy recommendations for improving rural development in Chaps. 3 and 4, and in this chapter, could also enhance the resilience of rural development. In villages with poor farmland resources, where the impacts of economic shocks are likely to be felt the most, those same policy recommendations that aim to assist farmer households in securing urban-based livelihoods could also reduce the impacts from economic shocks. Strengthening the levee system in important agricultural areas, where severe floods could cause a significant reduction in rice production, would minimize the chance for an occurrence of this worst-case scenario. Household decisions in villages with average farmland are sensitive to external influences, and policy can effectively stimulate land rental markets to further farmland consolidation. This would increase agricultural production and improve rural income in these villages. As their farmland becomes consolidated, it will become necessary to improve the levee and irrigation systems to mitigate potential flood impacts and promote agriculture.

Healthy macro development dynamics are important not only for improving rural livelihoods but also for enhancing the resilience of rural development. Technological advances are inevitable, and significant structural changes in the industrial sector could have impacts beyond rural households—they could affect the resilience of the whole economy if the structural changes lead to a great mismatch between the quality of labor and the demand of the industrial sector.

The development history of the western world shows that great depressions and recessions seem to have involved significant sectoral changes that are often a consequence of significant technological changes. Depressions and recessions may have started with crises in the financial or some other markets, but the impacts might have been contained had there been no significant sectoral changes that put considerable numbers of people out of work, greatly reducing overall consumption (housing included) and causing ripples across the entire economy for a lengthy period.

The rise of any new technology is likely to cause over-investments due to incomplete information and uncertainty, naturally creating some bubbles. The bursting of these bubbles can serve the purpose to filter out inefficient firms, not unlike natural selection, and may be a necessary part of economic development. This likely affects a relatively small number of firms and workers, with harm limited to a relatively small scope of the economy. Often the rise of a new technology also causes speculations in the financial markets. These speculations further inflate the "natural" bubbles, and bring more damage to the economy when the bubbles burst. Still, if the new technology does not result in significant structural changes in the industrial sector, the damage may not be devastating as a recession/depression.

The Great Depression in the 1920s, the dot-com bubble in the 1990s, and the great recession in the late 2000s are examples that illustrate these mechanisms and differences. The Great Depression involved a structural shift from agriculture to industrial development, and an industrial revolution of large-scale production. The dot-com bubble involved the rise of the high-tech industry; and the great recession may be seen as a broader manifestation of deepened impacts of the high-tech revolution on the whole economy. In fact, the impacts of the great recession in the late 2000s are still felt, and could deepen, because a relatively large segment of workers lost jobs, and those jobs are not very likely to come back amid globalization and the widening adoption of automated technologies.

Thus whether significant sectoral changes are involved may mark the difference between a recession/depression, and a crisis that is more associated with financial speculations on a rising new technology. The magnitude of structural changes and, consequently, the numbers of people affected may be key factors distinguishing a depression and a recession. There may be a threshold for the number of workers affected by structural changes that, once crossed, may lead to a phase transition. Further empirical work and modeling are needed and may indeed illustrate such processes. The Great Depression is relevant to development in China now, and may provide some lessons. If significant sectoral changes happen while a developing economy is in transition to a developed one, and rural-urban gaps are still large, the impacts could be dramatic. Developing and expanding various service industries could mitigate such potential impacts.

5.8 Robustness Analysis

To test how rental contracts between relatives affect the inferences on policy effects, a new model parameter, Pct Contracts without Payment, is introduced to represent the percentage of household agents that rent in farmland but do not pay for rental farmland. Its potential values range from 0 to 100%, with an increment of 10%. To examine how specific implementations of the grain subsidy policy may affect policy inferences, an alternative scenario under which grain subsidies are given based on contracted farmland areas—and which therefore do not affect planting decisions of farmers—is explored. These robustness analyses enhance our understanding of policy effects, but do not qualitatively alter the inferences on policy effects (Tian et al. 2016).

5.9 Limitations of the Model

A major limitation of the model is that it underestimates rural income in general. The model only includes major economic activities of rice cultivation and migratory work, excluding other activities, such as animal husbandry, cotton and vegetable production, and business. And it only examines direct payments to farmer households and does not include other types of subsidies, such as machine subsidies and price support. Additionally, as farming operations become larger, and as farmer households are assured of their long-term land-use rights, new and more profitable land-use practices will become feasible and can generate higher economic returns. This should further improve the agricultural system, especially in places with poor farmland resources.

Second, the way farmer households decide to sublease farmland for the long term in the model is not based on empirical data. Additional research is needed to investigate the conditions under which farmer households are willing to sign long-term contracts. Third, market prices for rice in the model remain constant. While China's price support policy helps stabilize prices for major agricultural products, future market prices for rice will likely change. Further modeling work is needed to explore how changes in rice price will increase uncertainty of rice production and interact with rising nonfarm wages to affect agriculture. This will generate more useful insights for promoting agriculture as wages increase, and may identify robust policy that produces satisfactory results across plausible scenarios.

Finally, the assumption that household agents do not hire labor can affect model outcomes. When farming operations grow, it is necessary to use hired labor, and large farms do hire laborers for commercial rice production. Allowing labor hiring would not change the inference that raising rural income will depend largely on nonfarm employments, because only few households' incomes would be improved. Allowing labor hiring would most likely intensify farmland concentration and consequently rice production. To the extreme, it would lead to the same maximum degree of farmland concentration as subsidizing large farms.

Under the policy scenario of subsidizing rice growers, the potential effect of labor hiring could be counterbalanced because most farmer households would be less willing to sublease their farmland to other households when receiving subsidies for growing rice. Under the policy scenario of subsidizing rental contracts, the potential effect of labor hiring could be enhanced, but the advantages of subsidizing rental contracts lie at lower wage levels. And at lower wage levels, it would better benefit all rural households to avoid extreme farmland concentration. The government may place some regulations to guide healthy labor hiring practices so that farmland concentration increases according to growth of the industrial sector and the amount of rural labor employed in that sector. As wages for nonfarm work rise, when most households in a village would no longer care about farming, subsidizing large farms would become an obviously better policy than subsidizing rental contracts. Therefore, allowing labor hiring in the model would not alter policy recommendations.

5.10 Conclusions

The model experiments in this chapter expand our understandings about rural development in the Poyang Lake area. They allow us to better understand the nature and potential effects of three subsidy policies on increasing rural income, promoting agriculture, and mitigating flood impacts, and particularly how these effects may change as wages for nonfarm work rise, and differ in villages with different farmland endowments. The experiments also demonstrate some of the possible impacts from economic and environmental shocks, and further illustrate the connections between rural and urban development. Overall, they provide useful insights about how policy may need to vary across local contexts and adapt at different stages of development to increase the well-being of rural households and promote agriculture amid social and environmental changes.

Agreeing with and enhancing the empirical analysis in Chap. 4, rural development in the PLR, and in China more generally, is closely linked to urban development. There is a limit on the degree to which farming can increase rural income, and raising rural income will depend largely on increasing nonfarm income. Urbanization will likely continue to play an important role in creating nonfarm work opportunities for rural households. Let us repeat here: It is important that policy interventions consider the quantity and the diversity in labor quality of rural populations to promote healthy urban-urban development dynamics and guide urbanization to benefit rural households.

Rising nonfarm income in the future may not naturally lead to farmland consolidation or consequently improved land-use efficiency—it can actually create challenges for agriculture. Farmland-rich villages contribute to rice production significantly more than do other villages and therefore are extremely important for food security. The good news is that intensive rice cultivation in farmland-rich areas will likely continue in the near future. Villages with average farmland resources are critical for increasing food production because their farmland potential is not fully realized yet, and household decisions can be influenced by policy incentives. At relatively low wage levels, subsidies could be given to households that sublease farmland to others to stimulate land rental markets in these villages. This rental subsidy policy would involve relatively low costs. Furthermore, the subsidy amount could be chosen to optimize current economic efficiency, or more usefully, be adjusted as development advances such that the degree of farmland concentration is in accord with the amount of rural labor employed in the industrial sector.

Subsidizing households managing large farms can achieve best outcomes in rice production and will likely become more effective as wages rise in the future. As young generations from rural areas are getting college education and settling in cities, their parents may no longer look at farming essential for their livelihoods. This generational transition facilitates growth of large farms and enhances the effectiveness of subsidies to large farms. Subsidies to rice growers, by contrast, are not effective in general, and may not be a good policy choice in the long run. But these subsidies are received broadly by rural households and make rural households feel that the government cares about them. This social effect of the grain subsidy policy is worth of consideration.

Many households in villages with poor farmland might become better off seeking urban-based livelihoods. Their livelihoods already rely largely on nonfarm activities; subsidizing households that sublease farmland to others for the long term could effectively facilitate farmland consolidation with low costs. Once consolidated, the marginal farmland could be used for alternative purposes to improve land productivity while reducing flood impacts. Such rental subsidies could also mitigate the issue of inequality in farmland resources for these villages and make every household in these villages grow economically more secure.

While severe floods could affect rice production in important agricultural areas for more than one year, the chance of this is relatively small. Economic shocks, such as economic crises, or dramatic technological changes in the industrial sector, especially if they lead to significant job losses for migrant workers, could produce more complex dynamics in rural development. Villages with poor farmland would be significantly affected by economic shocks; farmer income would be reduced to a very low level, and households could become extremely vulnerable to floods. Severe economic shocks would likely produce relatively large impacts on the dynamics of the land rental market in villages with average farmland. In all villages, the recovery of the agricultural system may not be fast or straightforward. The policy recommendations for improving rural development in general could also mitigate the potential impacts from economic and environmental shocks, enhancing the resilience of rural development in the PLR.

References

Axtell, R., & Epstein, J. M. (1994). Agent-based modeling: Understanding our creations. *The Bulletin of the Santa Fe Institute, 9*(2), 28–32.

Bloomberg Businessweek (2016, June 11). 东莞的周末静悄悄:机器人来了,工厂灯灭了. Retrieved September 01, 2016, from http://toutiao.com/i6294771976330281473 (in Chinese).

Brown, D. G., Robinson, D. T., An, L., Nassauer, J. I., Zellner, M., Rand, W., et al. (2008). Exurbia from the bottom up: Confronting empirical challenges to characterizing complex systems. *Geoforum, 39*, 805–818.

Deng, X., Huang, J., Rozelle, S., & Uchida, E. (2006). Cultivated land conversion and potential agricultural productivity in China. *Land Use Policy, 23*(4), 372–384.

Gale, H. F., Lohmar, B., & Tuan, F. C. (2005). China's new farm subsidies. USDA-ERS WRS-05-01.

Gale, H. F. (2013). *Growth and evolution in China's agricultural support policies* (USDA-ERS Economic Research Report, 153). Washington, D.C.: United States Department of Agriculture, Economic Research Service. Retrieved from http://www.ers.usda.gov/media/1156829/err153.pdf

Gao, L., Huang, J., & Rozelle, S. (2012). Rental markets for cultivated land and agricultural investments in China. *Agricultural Economics, 43*, 391–403.

Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W. M., Railsback, S. F., et al. (2005). Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science, 310*, 987–991.

Hazell, P. B., & Rahman, A. (Eds.). (2014). *New directions for smallholder agriculture*. Oxford: Oxford University Press.

Heerink, N., Kuiper, M., & Shi, X. (2006). China's new rural income support policy: Impacts on grain production and rural income inequality. *China & World Economy, 14*(6), 58–69.

Huang, J., Wang, X., Zhi, H., Huang, Z., & Rozelle, S. (2011). Subsidies and distortions in China's agriculture: Evidence from producer-level data. *Australian Journal of Agricultural and Resource Economics, 55*, 53–71.

Huang, J., Wang, X., & Rozelle, S. (2013). The subsidization of farming households in China's agriculture. *Food Policy, 41*, 124–132.

Lichtenberg, E., & Ding, C. (2008). Assessing farmland protection policy in China. *Land Use Policy, 25*(1), 59–68.

Liu, J., Liu, M., Tian, H., Zhuang, D., Zhang, Z., Zhang, W., & Deng, X. (2005). Spatial and temporal patterns of China's cropland during 1990–2000: An analysis based on Landsat TM data. *Remote Sensing of Environment, 98*(4), 442–456.

Ma, X., Heerink, N., van Ierland, E., Lang, H., & Shi, X. (2015). *Land rental market development in rural China—Impact of tenure security and trust*. Paper presented at the Annual World Bank Conference on Land and Poverty, Washington DC, March 23–27, 2015. Retrieved from https://www.conftool.com/landandpoverty2015/index.php?page=browseSessions&form_session=199&presentations=show

Otsuka, K. (2013). Food insecurity, income inequality, and the changing comparative advantage in world agriculture. *Agricultural Economics, 44*(s1), 7–18.

Otsuka, K., Liu, Y., & Yamauchi, F. (2014). *The future of small farms in Asia*. In Paper for Future Agricultures Consortium.

Rigg, J., Salamanca, A., & Thompson, E. C. (2016). The puzzle of East and Southeast Asia's persistent smallholder. *Journal of Rural Studies, 43*, 118–133.

Robinson, S. (1997). Simulation model verification and validation: increasing the users' confidence. In *Proceedings of the 29th conference on winter simulation* (pp. 53–59). IEEE Computer Society.

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS One, 6*(8), e23777.

Tian, Q., Holland, J. H., & Brown, D. G. (2016). Social and economic impacts of subsidy policies on rural development in the Poyang Lake Region, China: Insights from an agent-based model. *Agricultural Systems, 148*, 12–27.

Varian, H. R. (2002). Intermediate microeconomics: A modern approach. 6th ed. W. WNorton & Company. New York.

World Agricultural Organization (FAO's). (1990, 2000, and 2010). World Census of Agriculture (WCA). Retrieved from http://www.fao.org/economic/ess/ess-wca/en/

Yi, F., Sun, D., & Zhou, Y. (2015). Grain subsidy, liquidity constraints and food security-Impact of the grain subsidy program on the grain-sown areas in China. *Food Policy, 50*, 114–124.

Chapter 6
Sustainability of Human-Environment Systems

Abstract This chapter summarizes the findings from the study of rural development in the Poyang Lake Region and discusses their possible implications on sustainable development for other less developed rural areas. It also provides a more general framework for analyzing global sustainability.

Keywords Sustainable development • Vulnerability • Climate adaptation • Complexity science • Multiple research methods • Local and global sustainability

6.1 Sustainable Development in the Poyang Lake Region

6.1.1 Major Findings from the Study

This study has identified some of the complex processes that affect rural development in the Poyang Lake Region amid flood hazards. Rural households in the PLR are trying to improve their livelihoods in an increasingly urbanized and free-market economy that defines the broader development context of China. They have developed different livelihood strategies and have carried them out with varying degrees of success.

The variations in livelihood profiles and outcomes result by and large from the interactions between household characteristics (human and social capital, chiefly), and local social and environmental factors (particularly the availability and quality of farmland, a village's proximity to urban centers, and its social capital). Most households have few feasible employment options and rely on migratory work and rice cultivation as their major income sources. Certain household and village characteristics—notably, low education levels, and lack of village social capital and collective action—constrain their livelihoods.

Rural-urban development dynamics and institutional arrangements also affect rural livelihoods in important ways. While the small scale of farming operations constrains land-use possibilities and has a negative effect on agricultural production as well, the *hukou* system and insecure rights for rental land inherent in informal short-term rental contracts discourage farmland exchanges, further limiting the potential to raise farming income. Farm size is a potential lever of government

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0_6

policy; enlarging farming operations could significantly increase agricultural production, and improve rural livelihoods for some households. Raising rural income, however, will largely depend on increasing nonfarm income; farming can only improve rural incomes to a limited degree, even when all farmland is fully and most efficiently utilized.

Floods have considerable impacts on the region's overall development; however, variations in development at the household, village, and township levels do not correlate with flood risk. The livelihoods of most rural households in the PLR are not greatly affected by flooding because a large proportion of their income comes from nonfarm sources. But poor households are most affected since their livelihoods rely primarily on rice cultivation.

Although current agricultural practices appear sensitive to flooding, the degree of sensitivity—how severely their farming can be affected—varies across villages. Those with good, rich farmland are major rice production centers, generally protected by high-quality levees built and maintained by the government, and the sensitivity of their agricultural production is low. The agricultural system in areas where farmland is scarce and the soil is poor is highly sensitive to flooding because the levees there are often built by local people. The villages in these areas have greater development disadvantages and, under current policy, receive much lower subsidies for rice cultivation than do other villages.

At the township level (one level below counties and above villages), exposure and sensitivity to flooding are strongly correlated, with both increasing with proximity to the lake. Human development in a township is mostly associated with the degree of urbanization and distance to urban centers. There are large variations in these three dimensions of well-being among the 298 townships in the PLR.

Both severe floods and economic shocks can affect future rural development in the region. The greatest impacts of severe floods would be in reductions of rice production in the important agricultural centers, likely to last for multiple years. But the chances for a worst-case scenario are relatively small since these areas are protected by well-built levees. Rural development is thus likely to be resilient in the aftermath of severe flooding.

Economic shocks, such as dramatic technological changes or downturns in the industrial sectors, could produce more complex and longer lasting effects. Under these scenarios, the agricultural system could experience a series of adjustments as migrant workers return to the countryside, and recovery may be neither straightforward nor rapid.

Overall, villages with poor farmland resources would be significantly and more profoundly affected by economic shocks: farmer incomes would drop to very low levels, and farmer households could become extremely vulnerable to flooding. Economic shocks would also increase competition in the land rental markets, raising prices in all villages; severe economic shocks may produce relatively large effects on the dynamics of the land rental market in villages with average farmland resources.

6.1.2 Implications for Future Development and Policy Recommendations

These insights lead to some policy recommendations for national and regional governments. To promote rural development effectively, the central government must place the well-being of rural households at the center of its development policy, and guide urbanization for the benefit of rural households. There are multiple paths for rural households to develop successful livelihoods: focusing on urban work, specializing in agriculture, or maintaining mixed rural and urban livelihoods. These paths are all important, given the large rural population in China and its diversity in labor quality.

It is particularly important to promote simultaneous growth of agricultural and industrial sectors: As the industrial sector grows, more rural labor will be transferred from the agricultural sector, and households in the countryside can then enlarge their farming operations, improving agricultural income. Development, migration, and land policies need to foster such healthy rural-urban development dynamics synergistically throughout the course of urbanization.

While continuing to promote the development of the industrial sector in a way that facilitates the transfer of rural labor to the urban sector, the government could implement appropriate migration policies to encourage migrant workers who thrive in cities to settle there and exit agriculture. In the agriculture sector, it is important that the government continues its efforts in farmland consolidation, and ensures that concentration of farmland is in proportion with the amount of rural labor employed in the urban sector. The government could also promote local industrialization in rural areas, especially around smaller cities, to facilitate near-farm, high-return livelihood options for farmer households. Local industrialization may focus on activities that suit and take advantage of the natural environment, and integrate agriculture and local culture as well. This can help mitigate many issues associated with large-scale rural migration to large cities.

China's recent policy developments, i.e., the *hukou* reform that shifts toward residency registration systems in cities, the focus on development of urban clusters rather than large monocentric cities, issuance of land-use rights certificates to farmer households and extensions of their land contract periods, and special supports for large farms, seem to be appropriate and will likely contribute to healthy rural-urban development dynamics.

Yet as wages for nonfarm work rise, farmers will put more labor and effort in urban work, and this can have negative impacts on agriculture. The model experiments and experiences in some other Asian countries suggest that rising nonfarm income may not naturally lead to farmland consolidation and high land-use efficiency. Providing special supports to large farms is timely. As younger generations from rural areas attend college and settle in cities, many of their parents are willing to consider giving up farming. This facilitates the growth of large farms. The supports to large farms will likely become more important for promoting agriculture and produce wider effects as wages for nonfarm work become higher and more rural households focus on urban work.

The government could also subsidize farmer households that rent out their farmland long term under formal contracts before nonfarm work wages rise significantly. This alternative policy would involve relatively low costs and could encourage farmer households that do well in the cities to permanently settle there. The government could even adjust the subsidy amount as urbanization deepens to keep the pace of farmland consolidation synchronized with the transfer of rural labor to the industrial sector. This would also improve agricultural production in villages with average farmland resources, where farmland potential is not yet fully realized.

The current policy of subsidizing rice growers is generally not effective with all outcomes considered, and may not be a good policy choice in the long run. But these subsidies are broadly received by rural households and make farmers feel that the government cares about their welfare. This social effect is worth taking into consideration.

Development programs in the PLR could combine flood-mitigation efforts in various ways to promote the well-being of rural households. Facilitating rural households to develop robust livelihoods via different paths would raise rural income and enhance their ability to cope with flood impacts. Consolidation of farmland would make feasible those alternative agricultural practices that reduce flood impacts and improve land profitability. Poverty reduction programs should aim to develop the capabilities of poor households and help them build diversified livelihoods. This would reduce their dependence on crop cultivation and, consequently, the sensitivity of their livelihoods to flooding.

Providing additional assistance to households in villages with poor farmland and high flood risk in establishing secure urban livelihoods would not only improve their overall well-being but also address the issues of environmental inequality that have been exacerbated by levee construction and the current grain subsidy policy. The rental subsidy could further mitigate the environmental inequality in such villages. More generally, in the high flood risk zone, which contains one-fifth of the farmland in the PLR, the government could increase efforts to promote alternative land uses and livelihoods that particularly suit the characteristics of the local biophysical environments.

This study also sheds some light on how to improve future development and increase well-being for the townships, villages, and households in the PLR. While all the townships need to improve development, they should make development plans based on their specific situations. A clear understanding of exposure, sensitivity, and the various aspects of development can help township-level governments make appropriate adjustments.

Specifically, those townships with low exposure to flooding, but which also have low levels of development, should examine the social systems for ways to improve human development. Townships whose degrees of sensitivity are greater than their exposure should examine their land-use and development patterns carefully to further reduce sensitivity. Townships with both high levels of development and high degrees of exposure and sensitivity must pay particular attention to levee engineering works, in addition to making appropriate adjustments to development. All township-level governments need to look at the broader aspects of development beyond narrow economic measures of income.

With respect to villages, it is essential that village leaders consider local characteristics. Specifically, villages endowed with special types of natural resources must look ahead and plan how to invest their accumulated capital from those natural resources to develop alternative sustainable livelihoods. Villages with scarce, poor farmland and high exposure to flooding may take advantage of the urbanization process to migrate out, and many village households may become better off building urban-based livelihoods. To achieve a successful out-migration, they must be well informed about and prepared for urban job markets. Villages with average farmland can further improve household income and increase land-use efficiency through farmland consolidation. All villages could develop near-home nonfarm work opportunities to complement farming income. This would likely involve collective action of farmer households, and all village leaders must work on fostering collective action.

Rural households have developed their livelihoods based on their own characteristics and local contexts. Each of the four livelihood profiles—diversified near-home livelihood, business-oriented livelihood, farming-based livelihood, and migratory work and farming combined livelihood—can produce high household income. Location near urban centers and rich farmland contribute to successful diversified near-home and farming-based livelihoods. But in general, rural households could strengthen their human and social capital to improve their livelihoods. Investing in education and training in particular will improve labor competitiveness in urban job markets and produce long-term economic returns.

Rural households also need to pay attention to collaborative efforts because individually they are less capable of overcoming the constraints found at both individual and system levels. A village's social capital can significantly affect the livelihoods of all its households but is also shaped by the human and social capital of individual households.

Finally, by examining rural livelihoods within the broader national development context, emphasizing differences in local conditions, and addressing the sensitivity of rural livelihoods and agriculture to flooding, these recommendations on improving rural development can also enhance the resilience of rural development amid social and environmental changes.

6.2 Implications for Sustainable Development in Other Rural Areas

Two lessons learned from the PLR study could be useful for promoting rural development in other less developed areas that are affected by climate impacts.

1. *Development programs and policies at multiple levels are necessary to create favorable macro and micro development environments in which rural households with different characteristics can develop robust livelihoods via different paths.*

   Individual households have limited capabilities, and sustainable development in such areas may even exceed the capabilities of regional governments. The national development context that includes industrial development, agricultural development, and policy and institutional settings can greatly affect the livelihood options for rural households, the choices they make, and ultimately their well-being. Physical infrastructure, such as engineering work, at regional and local levels can also play an important role in mitigating environmental impacts on rural livelihoods.
2. *Policy interventions will better promote development if they differentiate across places to suit local situations and adapt over time to changing situations.*

   The land-use and livelihood decisions of rural households are affected by local environments, and therefore it may require different policies in different places to achieve the same goal. Policy can also play different roles or have different goals in different places. There is hardly a straight pathway to sustainable development, and policy adjustments are necessary to ensure the system move on the right direction and gradually get to more desired states.

Of course, specific policy recommendations on rural development are likely different for different regions. Each region has unique characteristics in natural and human resources and in the broader development context. And each must develop accordingly. As Eleanor Ostrom wrote in "Green from the Grassroots," published the day she passed away in 2012, there is no panacea to the sustainability crisis; a variety of overlapping policies at different levels are more likely to succeed than a single overarching plan.

Even so, several general principles may apply to other similar rural areas. First, nonfarm employment is likely to be important for improving rural livelihoods across the developing world—and not just as a means of income diversification, but as a fundamental part of rural livelihoods. Urbanization plays an important role in creating nonfarm employment opportunities for rural labor, and it is important that governments guide urbanization to benefit farmer households and truly improve their well-being. Promoting simultaneous growth of the agricultural and industrial sectors and healthy rural-urban development dynamics could facilitate the transfer of rural labor to the urban sector.

Second, rural households in marginal natural environments might take advantage of urbanization to migrate out, and governments could offer them assistance in developing urban-based livelihoods. Meanwhile, system-level engineering work is important for mitigating climate impacts in areas where agriculture is important and rural livelihoods are highly dependent on farming. Large-scale engineering projects, such as levee systems, often require collective action and significant investments beyond the capacity of individual households or villages. Financial and organizational support from governments will be crucial for such engineering work.

Governments could also play an important role in researching and developing sustainable land uses.

Third, land privatization may or may not be an appropriate approach to promoting the well-being of rural households. More generally, there is no single absolutely "right" institutional arrangement, and which institutional arrangement works best depends on the specific situation and timing. There are multiple policy instruments that governments can use to promote the well-being of rural households, address issues of inequality, and prevent rural poor becoming urban poor. And governments are more likely to succeed in tackling development issues with a comprehensive policy plan than relying on any single measure.

6.3 From Vulnerability to Sustainability

The PLR study demonstrates how the new sustainability framework—assessing well-being, investigating the complex processes underlying well-being, and exploring future paths—can be implemented to analyze coupled human-environment systems (CHES) in a specific place. Using a complex systems approach, the framework integrates social, economic, institutional, and environmental perspectives. This allows us to acquire rich insights about the micro- and macro-level processes in CHES and provide scientific support for policy to promote sustainable development.

By treating climate as one of the many factors that affect human development, and emphasizing human well-being, a broader concept than vulnerability, this study sheds light on how to simultaneously improve human development and reduce climate impacts. Policy and broad development context is as important for rural development as for climate adaptation and vulnerability reduction. In less developed areas that are exposed to extreme climate events, reducing vulnerability, enhancing adaptive capacity, and promoting human development are essentially linked; climate adaptation and vulnerability reduction may have limited effects without addressing development (Kates 2000; Adger et al. 2003; Eakin 2005; Agrawal and Lemos 2015; McCubbin et al. 2015; Warner et al. 2015). This sustainability framework encompasses all three issues and addresses them together.

The PLR study also demonstrates that geospatial assessments, empirical analyses of causal mechanisms, and modeling are all useful; they complement one another to provide scientific support for policymaking. When we study complex systems like coupled human-environment systems, no single method is likely to be sufficient. Each research method has its strengths and limitations. Each provides understanding about some aspect of a system. We can combine different research methods to gain deeper understandings about a CHES. This is very much like home maintenance: a hammer is an extremely useful tool for fixing things around the house, but it cannot fix a leaky pipe. And that's why we keep a toolkit handy from which we can draw whatever tools fit the situation.

6.4 A General Framework for Analyzing Global Sustainability

Significant challenges exist for both developing and developed areas in other dimensions of sustainability: land use, natural resources, energy, pollution, human health, etc. And the world has become increasingly interconnected and telecoupled (DeFries et al. 2010; Seto et al. 2012; Liu et al. 2013; Meyfroidt et al. 2013; Verburg et al. 2013; Seto and Reenberg 2014). All these challenges beg for examining sustainability broadly and globally (Levin and Clark 2010; Brondízio and Moran 2012; DeFries et al. 2012; Ostrom 2012; Moran and Lopez 2016).

This section describes a more general framework for analyzing sustainability. The overall objective is to understand the fundamental processes underlying sustainability at both local and global levels. I provide the definitions of local and global sustainability, and propose some broad research questions and general approaches to address these questions.

I continue to use a complex systems approach to examine coupled human-environment systems. This approach, I believe, can lead to important new understandings about sustainability. The framework is centered on the micro-socioeconomic foundations of long-term economic growth. It treats the natural environment as an endogenous entity and looks at multiple dimensions of human and environmental well-being (Fig. 6.1a). It views scales as networks of interacting human-environment systems and examines their interconnectedness (Fig. 6.1b).

6.4.1 Definitions and System Properties

Local sustainability: Human well-being in a specific place achieved a certain level and continues for many generations (forever, theoretically).

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

Global constraints: Natural resources of each kind are limited at a given time, with some decline over time.

Local constraints: Natural resources of each kind are limited at a given time, with some decline over time.

Diversity of places: Each place has specific characteristics, in terms of natural resources, geography, human resources, technologies, institutional and cultural settings, political systems, and development history. Technology affects not only efficiency of production, but environmental impacts as well.

Interconnections between human and environmental well-being: (1) Production and consumption have environmental impacts; (2) Degraded environmental well-being affects production (e.g., degraded soils reduce agricultural output) and human well-being (e.g., health and spiritual satisfaction).

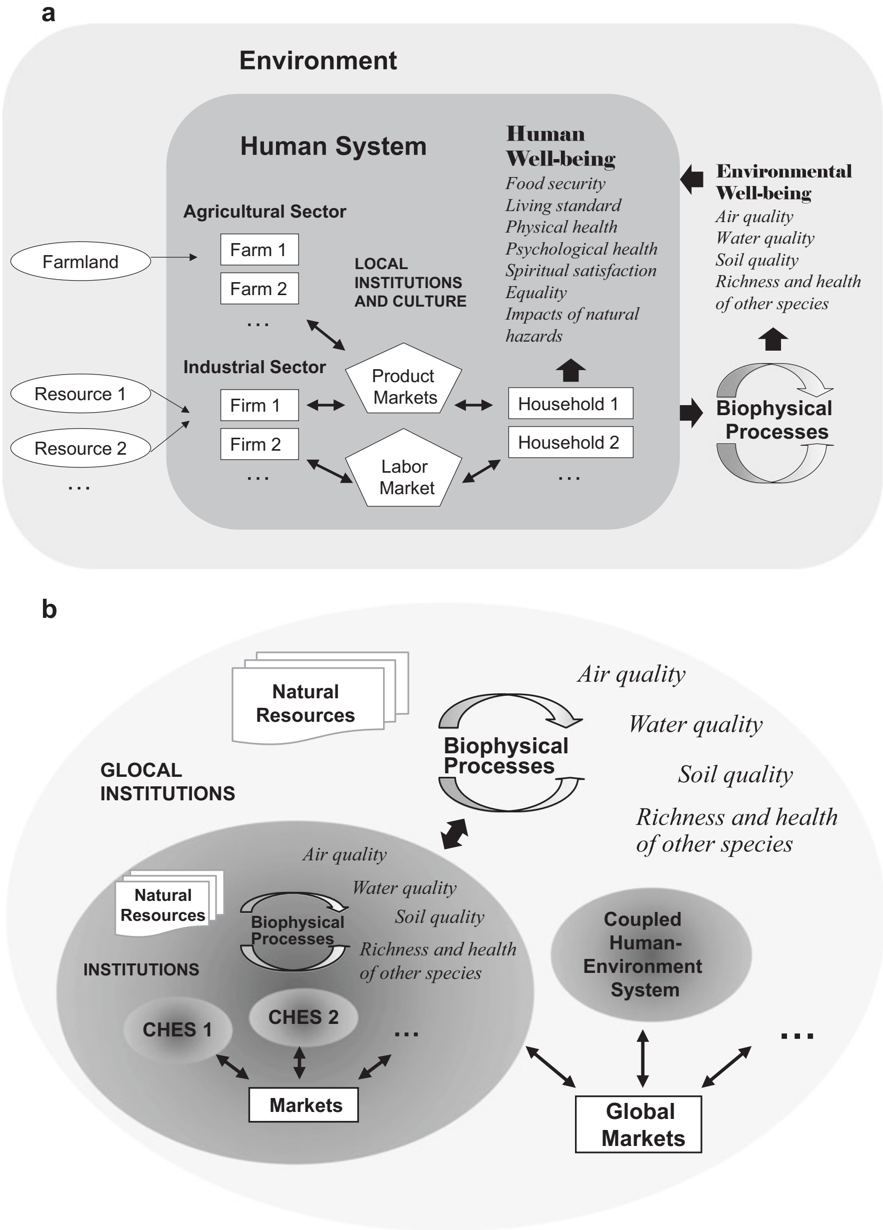


Fig. 6.1 (**a**) A general framework of sustainability: CHES in a specific place. (**b**) A general framework of sustainability: linkages between CHES.

Interconnections between places: (1) Environmental impacts can spread from local places to affect global environmental well-being and human well-being in other places; (2) Trade of materials and products, and the way local places use natural resources, can affect human well-being at the global level and in other places (e.g., using farmland to grow corn for ethanol fuel affects local and global food security).

Trade-offs: (a) between present and future economic growth; (b) between human well-being and environmental well-being; (c) between different dimensions of human well-being; (d) between local sustainability and global sustainability; (e) between different ways of using accumulated capital: consumption, reducing environmental impacts, and investing in research and technology etc.

6.4.2 Broad Research Questions and Approaches

The following are some important questions we can ask to investigate the fundamental processes underlying local and global sustainability. By understanding the processes and, in particular, their interconnections, we may be able to decide appropriate trade-offs and shape human-environment systems toward a sustainability transition.

Like Robert Lucas Jr. (2004), who finds it "hard to think about something else," many economists—from Adam Smith (1776) to Sir Arthur Lewis (1954), Robert Solow (1956), Paul Romer (1986), Jeffery Sachs (1997), Robert Barro (1998), William Easterly (2001), Daron Acemoğlu (2002), and Justin Yifu Lin (2009)—have looked at the causes of economic growth and advanced our understanding from various perspectives. Yet developing countries are largely unsuccessful in making the transition to developed economies. Developed economies also face slowdowns in growth and problems of periodical crises.

Economic growth is an outcome of the *interplay* of many factors and forces, and is path-dependent (Arthur 1994, 1997; Nelson 1995; Root 2013). So *how do various factors and forces in natural resources, geography, human resources, institutions, cultures, technologies, trade, etc., interact with one another through the decisions of individuals, households, and firms to drive long-term economic growth in a given place?* Using a complex systems approach to examine these interactions alongside specific development history may generate new insights about the fundamental processes of economic growth, the mechanisms through which innovations promote growth, and the deep causes for economic crises. Such insights can have important policy implications.

Along this line, another important question is: *Can developing economies catch up with developed economies in a highly interconnected world, and how?* The Dependency theory 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). This seems to suggest that less developed economies may not be able to catch up with developed economies. But the success of Four Small Dragons (Taiwan, South

Korea, Hong Kong, and Singapore) and Justin Yifu Lin's sector-based economic models provide a different outlook.

The global economy is a complex adaptive system of which every country is a part, and a complex systems approach helps us to better analyze the interconnections among all economies and, possibly, to identify viable strategies for less developed countries to advance their economic development amid globalization. The growth of the global economy results from the contributions of all economies, and the "multiplier effect" at the global level depends on the diversity of these economies.

It is important that a country understands its position in the global system, as well as its characteristics, because by doing so, it can best contribute to the global economy and benefit from trades. The global economy has evolved into multiple hierarchies beyond the dichotomy of developed and developing economies. The global interdependency makes national policy more important than ever, not only for countries at lower levels of the hierarchies to advance their economies amid globalization, but also for developed countries to mitigate rising domestic inequality that is partially attributed to globalization.

Now we can add environmental impacts and examine human-environment interactions to address questions of local and global sustainability. *How do different ways of using resources at local places affect local and global sustainability? What local development strategies and global institutions facilitate local and global sustainability?* Using a complex systems approach, we can explore global consequences of local actions and the effects of institutions on individual actions.

Another related question is: *Can sustainability in a specific place endure separately from other places?* There will always be variations between places, with some having higher levels of well-being than others. The sustainability in some places at times may rest on the unsustainability of other places. However, because of the global constraints in natural resources and the interconnectedness between places, sustainability in a specific place may no longer be possible when all other places become unsustainable. Local sustainability and global sustainability are intertwined, just as individual economies and the global economy are.

A sustainable future depends on how far ahead and how large a scope we can, or are willing to see. Because we are all linked within the global system, focusing solely on local and near-term interests will lead inexorably to global unsustainability and local unsustainability in the long run. Thus we may further ask: *How can we effectively foster cooperation to achieve global sustainability? Are there win-win solutions for all parties? How may we balance competition and cooperation in promoting economic growth and sustainability?*

Probably nobody would reject the value of competition for innovation. But I have no doubts that as the world becomes increasingly interdependent, cooperation will become necessary and important for solving many pressing issues humanity faces, including sustainability. Competition is not the only means to foster innovation, and other institutional arrangements, such as provision of certain levels of security, could encourage individuals to take risks associated with innovation and fully realize their creativities. This is another areas where a complex systems approach can shed light on.

And it is essential to pay particular attention to urban development. Urbanization proceeds rapidly across the developing world. Currently, 54% of the world's population lives in urban areas (UN 2014). It is estimated that the proportion of the world's urban population will rise to 66% by 2050, and that about 90% of the increase will be concentrated in Asia and Africa. *How are we going to guide urbanization to develop sustainable cities?*

Driven by growth, the developing world has witnessed the birth of "mega-cities," and "global cities" built on "master plans." But the implications of this development for governance and the well-being of people and the environment are not well understood. In many cases, the master plans ignore local characteristics (Chakravorty 1996; Robinson 2002; Marshall 2003; McKinsey and Company 2009; Ilesanmi 2010). Cities have their intricate inner workings, and the diversity in land use and buildings in neighborhoods is fundamental to a vital economy, healthy social life, and even people's safety (Jacob 1961, 1968; Holston 1999).

Urban development involves actions and interactions of many human agents; general guidelines are likely more effective and useful than master plans. Using a complex systems approach, we can test planning scenarios and perhaps develop guidelines for urban development such that the many human agents collectively make sustainable cities, i.e., cities that are economically vital, environmentally and people friendly, adaptable and resilient.

To address these questions, we need *empirical studies* and *synthesis*. Case studies that examine the coevolution of the natural environment, human behaviors, cultures, institutions, and development can provide empirical understanding about processes in human-environment systems. From these we can develop models to explore interactions among human agents and between social and environmental components, interconnections among places, and trade-offs between human and environmental well-being and between local and global sustainability. Agent-based and network approaches are particularly useful in this regard. We can expand the work on agent-based computational economics (ACE) that models economic processes as dynamic systems of interacting agents (see Tesfatsion and Judd 2006; Gintis 2007; Deissenberg et al. 2008; Mandel et al. 2009; Axtell and Guerreto 2017). The insights the models generate may further guide the direction of empirical research.

References

Acemoğlu, D., Johnson, S., & 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.

Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in Development Studies, 3*(3), 179–195.

Agrawal, A., & Lemos, M. C. (2015). Adaptive development. *Nature Climate Change, 5*(3), 185–187.

Arthur, B. (1994). *Increasing returns and path dependence in the economy*. Ann Arbor: University of Michigan Press.

Arthur, B. (1997). The economy as an evolving complex system II. In S. Durlauf & D. Lane (Eds.). Series in the Sciences of Complexity. Reading: Addison-Wesley.

Axtell, R., & Guerreto, O. (2017). *Dynamics of firms: Theory, data, and models*. London: Oxford Press.

Barro, R. J. (1998). *Determinants of economic growth: A cross-country empirical study*. Cambridge: MIT Press.

Brondízio, E. S., & Moran, E. F. (Eds.). (2012). *Human-environment interactions: Current and future directions* (Vol. 1). Dordrecht: Springer Science & Business Media.

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.

DeFries, R. S., Rudel, T., Uriarte, M., & Hansen, M. (2010). Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience, 3*(3), 178–181.

DeFries, R. S., Ellis, E. C., Chapin, F. S., Matson, P. A., Turner, B. L., Agrawal, A., et al. (2012). Planetary opportunities: A social contract for global change science to contribute to a sustainable future. *BioScience, 62*(6), 603–606.

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

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

Easterly, W. R. (2001). *The elusive quest for growth: Economists' adventures and misadventures in the tropics*. Cambridge: MIT Press.

Gintis, H. (2007). The dynamics of general equilibrium. *The Economic Journal, 117*, 1280–1309.

Holston, J. (1999). The modernist city and the death of the street. In S. Low (Ed.), *Theorizing the City: The new urban anthropology reader* (pp. 245–275). New Brunswick: Rutgers University Press.

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*. New York: Vintage Books.

Jacob, J. (1968). *The economy of cities*. New York: Vintage Books.

Kates, R. W. (2000). Cautionary tales: Adaptation and the global poor. In *Societal adaptation to climate variability and change* (pp. 5–17). Dordrecht: Springer.

Kláren, P. F. (1986). Lost promise: Explaining Latin America underdevelopment. In P. F. Klaren & T. Bossert (Eds.), *Promise of development, theories of Change in Latin America*. Boulder: Westview Press.

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

Lewis, W. A. (1954). Economic development with unlimited supplies of labor. *Manchester School of Economic and Social Studies, 22*, 139–191.

Lin, J. Y. (2009). *Economic development and transition: Thought, strategy, and viability*. Cambridge: Cambridge University Press.

Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., et al. (2013). Framing sustainability in a telecoupled world. *Ecology and Society, 18*(2), 26.

Lucas Jr., R. E. (2004). *Lectures on economic growth*. Cambridge: Harvard University Press.

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

Marshall, R. (2003). Ch. 8: Doi Moi and the ascending dragons of Vietnam: Hanoi North and Saigon South. In*Emerging urbanity: Global urban projects in the Asia Pacific Rim* (pp. 120–148). London: Routledge.

McCubbin, S., Smit, B., & Pearce, T. (2015). Where does climate fit? Vulnerability to climate change in the context of multiple stressors in Funafuti, Tuvalu. *Global Environmental Change, 30*, 43–55.

McKinsey and Company. (2009). Preparing for China's urban billion. Retrieved from http://www.mckinsey.com/mgi/publications/china_urban_billion

Meyfroidt, P., Lambin, E. F., Erb, K. H., & Hertel, T. W. (2013). Globalization of land use: Distant drivers of land change and geographic displacement of land use. *Current Opinion in Environmental Sustainability, 5*(5), 438–444.

Moran, E. F., & Lopez, M. C. (2016). Future directions in human-environment research. *Environmental Research, 144*, 1–7.

Nelson, R. (1995). Recent evolutionary theorizing about economic change. *Journal of Economic Literature, 33*(1), 48–90.

Ostrom, E. (2012). Green from the grassroots. *Project Syndicate*.

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

Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of Political Economy, 94*(5), 1002–1037.

Root, H. L. (2013). *Dynamics among nations: The evolution of legitimacy and development in modern states*. Cambridge: MIT Press.

Sachs, J. D., & Warner, A. M. (1997). Fundamental sources of long-run growth. *The American Economic Review, 87*(2), 184–188.

Seto, K. C., Reenberg, A., Boone, C. G., Fragkias, M., Haase, D., Langanke, T., et al. (2012). Urban land teleconnections and sustainability. *Proceedings of the National Academy of Sciences, 109*(20), 7687–7692.

Seto, K. C., & Reenberg, A. (2014). *Rethinking global land use in an urban era*. Cambridge: MIT Press.

Smith, A. (1776). *The wealth of nations*. Chicago: University of Chicago Press.

So, A. Y. (1990). *Social change and development: Modernization, dependency and world-system theories*. Newbury Park: Sage.

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

Tesfatsion, L., & Judd, K. L. (Eds.). (2006). *Handbook of computational economics, Vol. 2: Agent-based computational economics, Handbooks in economics series*. Amsterdam: Elsevier/North-Holland.

United Nations (UN). (2014). *World urbanization prospects 2014: Highlights*. New York: Department of Economic and Social Affairs, Population Division, United Nations.

Verburg, P. H., Mertz, O., Erb, K. H., Haberl, H., & Wu, W. (2013). Land system change and food security: Towards multi-scale land system solutions. *Current Opinion in Environmental Sustainability, 5*(5), 494–502.

Warner, B. P., Kuzdas, C., Yglesias, M. G., & Childers, D. L. (2015). Limits to adaptation to interacting global change risks among smallholder rice farmers in Northwest Costa Rica. *Global Environmental Change, 30*, 101–112.

Chapter 7
The Complex Systems Approach to Policy Analysis

Abstract In this chapter, I reflect on the complex systems approach to policy analysis and discuss how to develop useful, credible agent-based models for policy analysis. The chapter concludes the book with a conjecture about sustainability of complex adaptive systems in general.

Keywords Complex adaptive systems • Policy analysis • Agent-based modeling • Niches • Resilience • Sustainability

7.1 The Sustainability Framework and Complex Systems Approach to Policy Analysis

The basic idea of the sustainability framework is to (1) assess the state of a system, using multiple variables; (2) understand causal mechanisms, i.e., how human agents act and interact with one another to shape the state of the system; and (3) explore how to influence individual decisions such that they collectively move the system toward desired states. These steps need to be repeated over time to provide insight for policy to steer a system gradually toward desired states. This idea is applicable to other complex adaptive systems.

Most important for policy interventions in complex systems is to ensure that a system is moving on the right track. After all, it is difficult to make long-term point predictions for a complex system because its state is being shaped by adaptive actions and interactions of many agents, and can change in unforeseen ways. Nor is there an optimal policy that will cause a system to move linearly, from its current state to a desired state at once. Adjustments will have to be made along the way to correct the course of the system, or accelerate or slow certain effects.

This kind of "adaptation mentality" is essential to the policymaking process. To use an analogy from Brian Arthur, the policy-maker is like a captain of a paper boat drifting down a river; at his best, he watches the currents and the changing flow, and uses his oar to "punt from one eddy to another" (see Mitchell 1992). And this is precisely why agent-based modeling is useful: it offers insights about the directions of "flow." In the next section, I will try to illustrate how to develop agent-based models that generate *new*, *useful*, and *convincing* insights for policy analysis.

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0_7

7.2 Agent-Based Modeling for Policy Analysis

7.2.1 Design Useful Models and Ask Meaningful Questions

An agent-based model simulates the decisions of heterogeneous agents in a complex adaptive system, and is an analytical tool for studying these systems. To develop a useful agent-based model, we need to ask good research questions—without those, the model can easily become a mechanical simulation that does no more than mimic a real system. Mechanic simulations may look realistic, but they are not particularly useful.

In any field, theories guide us to ask questions. So, too, theories of complex adaptive systems (Holland 1995, 1998, 2012) will help us to pose meaningful questions about these systems. Understanding their key features and relevant concepts can be useful for policy interventions in a broad sense, and for modeling in particular (OECD 2009).

In a complex adaptive system, the agents learn and adapt through interactions with other agents, leading to adaptability of the system. This means that policy needs to adapt over time to suit new situations and nudge a system toward more desired states, and how policy should adapt is an important research question. Agent-based models can offer useful insights for adaptive policymaking.

Complex adaptive systems often exhibit non-linearity, i.e., system-level novel patterns cannot be predicted just by summing the properties and actions of individual agents in the system. Policy may produce unintended consequences if it does not account for adaptive interactions of agents that have distinctive characteristics and experiences, and their coevolving behaviors. *These systems can have lever points at which a small intervention produces large changes in system-level outcomes.* Such lever points can be exploited by policy to influence the system cost effectively. Agent-based models can be used to explore policy levers and unintended consequences of certain policy.

A complex adaptive system usually has a large state space. The system can evolve in many different directions, and sometimes a *robust policy* that delivers satisfactory results across plausible future scenarios is more desirable than a policy that produces best outcomes only for some scenarios (Lempert 2002). *A system can exhibit non-equilibrium or multiple equilibriums, with tipping points that propel it into a sudden phase transition*. Tipping points may present policy challenges if a system is currently in a desirable state; they may present opportunities if other attractors represent more desirable states. In such cases, we can use agent-based models to simulate future scenarios, explore the state space of a system, and identify tipping points or robust policy.

The behavior of a complex adaptive system is path-dependent, i.e., dependent upon its initial conditions and previous states. It can therefore be locked on a long-term undesirable path. Inferior technologies, for example, sometimes prevail because they had an early advantage, while innovations in general are difficult to introduce early on. Policy can influence the future path of a system by helping to break existent patterns and promote the adoption of an innovation at the initial stage. Timing is important for these interventions, and models can explore the appropriate timing of interventions.

Complex adaptive systems tend to self-organize often without a central control. But individual actions and interactions in a system may not necessarily lead to optimal system-level outcomes. Just think about the Prisoner's Dilemma and the Tragedy of the Commons. This is why policy is necessary, but policy can effect changes in a system more effectively, by setting up incentives that induce individual decisions to collectively lead to desired outcomes. Agent-based models can be used to explore the potential effects of alternative policy.

Although coherent behaviors can and often do emerge from individual actions and interactions, complex systems can fall into a state of chaos. Policy could play a role in preventing disastrous outcomes associated with chaos. Agent-based models cannot prove that certain things will happen, but they can demonstrate possible outcomes. Identifying conditions that lead to disastrous outcomes could be a powerful use of models and would provide insights for policy interventions to prevent disastrous outcomes.

These are some policy insights a complex systems perspective offers and some potential uses of agent-based modeling for policy analysis. Central to all these is the need to understand the micro-level processes and dynamics in complex adaptive systems.

7.2.2 Meet the Challenge of Conceptualization

The strength of agent-based modeling lies in its ability to capture agent diversity, interactions between agents, and the feedback between individual behaviors and global states (Epstein and Axtell 1996; Gilbert 2007; Manson and Evans 2007; Miller and Page 2007; Farmer and Foley 2009; Railsback and Grimm 2011; Cioffi-Revilla 2014; Walsh and Mena 2016). This is also why agent-based models can generate new and sometimes surprising insights about a system.

For example, Schelling's classic segregation model (1971) illustrates an important insight that neighborhood segregation can happen even if individuals only have a slight preference to be near people of their own race. The segregation pattern generated by his model would not have been predicted by simply adding up individual attitudes, but emerged from their interactions.

The farmer household model in this study also shows some interesting patterns of change for farm sizes as nonfarm work wages rise. These patterns emerge due to interactions, particularly the interacting influences of wages and the land rental market. That rising nonfarm income may not naturally lead to farmland consolidation and increased scale of farming operations in the countryside, as economists would expect, has policy implications.

However, because agent-based models represent the micro-level processes of real systems, this create challenges for conceptualization, validation, and communication with non-ABM modelers (Parker et al. 2003). Conceptualization in particular is crucial to modeling success: where to draw the system boundaries, what components to include, how to represent agents, including their decision making, and what is the appropriate level of abstraction etc.

Meeting these challenges is even more critical for policy analysis. To convince policy-makers, we need high levels of confidence in our models. To develop a credible model, model conceptualization should be based on a good understanding of the system in question. A good understanding of a specific system can, in the first place, help us ask research questions that are important and meaningful for that system. Generally speaking, a conceptual model should capture the real system sufficiently to address intended research questions.

Use Empirical Methods to Inform the Development of Models

A variety of empirical research methods are available to increase our understanding of complex systems and inform the development of agent-based models. These methods can (1) provide insights into the micro-level processes and dynamics of a system, including agent decision making; (2) provide data for setting a model's parameters, and for initializing various components of the model, e.g., agent types, distributions of agent attributes, environmental attributes, values of exogenous entities; and (3) provide insights and data, including qualitative or quantitative macro-level patterns, for model validation. *In-depth case studies*, *large N statistical analyses*, *experiments* used in behavioral economics, *participatory research* that involves shareholders, and *qualitative approaches* can each give us valuable, albeit different, insights into a system (Janssen and Ostrom 2006; Robinson et al. 2007).

Case studies, as used in this Poyang Lake project, can provide detailed information about the processes and dynamics of a system. But case studies tend to be system-specific and lack generality. *Large N data analyses* can be used to derive general patterns of individual motivations and behaviors, providing detail on how to populate agents in a model. They are not so good, however, at revealing mechanisms and processes. Nonetheless, they are attractive because data can be easily available from a census and, increasingly, from electronic sources, besides surveys.

Experiments can test specific hypotheses about human behaviors, informing the decisions of agents in a model. But in general they are vulnerable to weaknesses in subject representativeness, contextual information, controlled experiment environments, and credibility of the answers (e.g., Berg et al. 1995; Kurzban and Houser 2005; Houser et al. 2008; Cotla 2016). *Participatory approaches* enable researchers to discover rich information about agent decisions and interactions, and even to uncover policy from the bottom up, but they can be costly and are often limited to relatively small scopes (e.g., Castella et al. 2005; Van Berkel and Verburg 2012).

Qualitative approaches can be very useful, too. For example, Jane Jacob (1961) provides a convincing account, based on her intense observations of urban life, of how economic prosperity and public safety emerge from mixed land use and the interactions of its inhabitants. What she describes is essentially a qualitative agent-based model, with detail beyond the capacity of a computer simulation. In this PLR study, field observations and qualitative analysis of the interviews also yield important insights about farmer households' decisions concerning land use and livelihoods.

Despite all that capability of agent-based models, we should not expect to discover important insights solely from these computer experiments. Of greater importance from the onset is that we develop a good understanding, even an intuition, about the system we wish to explore, based either from our own empirical research or the theories and empirical work of others. Models are analytic tools we use to formalize our intuitions and improve our understandings about a system. While we should try to make modeling technically rigorous, we need broad and deep grasp of an issue to convince policy-makers of a model's usefulness, and ultimately influence policymaking.

Decision Theory and the Representation of Agent Decision Making

Understanding how the agents in a system make decisions is particularly important for policy analysis. It is this understanding that enables policy-makers to improve macro-level processes for individual agents, or to design "smart" policy to influence individual behaviors, facilitating change toward more desired states. From a complex systems perspective, the role of policy is not to impose a central control, but to introduce incentives to induce individual decisions and actions such that they collectively lead to desired system-level outcomes. In addition, top-down interventions have become increasingly unpopular and tend to provoke bottom-up resistance, leading to difficulty in implementation and high enforcement costs.

Researchers in various disciplines examine human decision making through different lenses. Economists, for example, have developed rational choice theory, according to which people weigh the costs and benefits, and choose the option that gives them the best utility, assuming people have complete information about the choices and consistent preferences (Hogarth and Reder 1987). Psychologists, however, emphasize the irrationality of human behavior and consistently find bias in human decisions, especially with heuristics (Tversky and Kahneman 1975). Behavioral economists try to bridge the economists' rationality and psychologists' irrationality, and their experiments have mostly illustrated the foundation of human rationality, with some exceptions (Smith 2005).

Coming under the general framework of rational choice is the notion of bounded rationality, which argues that individuals are rational decision makers, but they may not always have complete information about their options or possess consistent preferences over choices, or have the computational power to make optimal choices (Simon 1956). Individual choices are however hardly made independently; rather they are influenced by social and cultural forces. Social economists thus see social influences over individual decisions everywhere (Becker and Murphy 2009). Sociologists, with deep roots in empiricism, and development economists in the field, often find that societal structures play a large role in affecting or constraining individual choices (Scott 1977; Susan 1977; Sen 1981; Blaikie et al. 1994).

So what should we take from these divergent theories and perspectives? We may start with the assumption that people are rational decision makers, and look for empirical evidence to verify this assumption. If the evidence suggests otherwise, that people are not making rational choices, we will need to investigate further. Are they trying to optimize? Do they have unusual or different preferences? Are they constrained by a lack of information or computational capabilities?

People can still be rational decision makers, even when they do not appear to be rational or seem to use simple heuristics. The majority of farmer households in the Poyang Lake Region, for example, appear to rely on a few heuristic rules in labor allocation: young male adults work in the city, while old people and some women cultivate rice on the farm. Yet in conversation, the farmers show that they are actually rational decision makers: They are trying to achieve the optimal economic result and have done what they can.

Farmers in the PLR are aware of other land-use and livelihood options, and the costs and benefits associated with these options. They can explain how they derive the costs and benefits. Not much calculation is needed for labor allocation to optimize total income, either; household members have just two choices—work in the city or work on the farm. Because migratory work tends to produce higher returns, a household member chooses to work in the city as long as possible. Members who cannot find work in the city naturally stay on the farm and cultivate rice. It happens that young people and male adults are more likely to find work in the city.

Thus, while many empirical cases contradict perfect rationality, there is plenty of evidence to suggest that a peasant's behaviors exhibit an attempt to improve the household livelihood (Strauss and Thomas 1995). What appears to be irrational may be the result of a complex exercise in rationality, and can often be explained with deeper probes into the nature of constraints or preferences.

Of course, not all decisions are "rational," as defined by rational choice theory. We have all analyzed the pros and cons for some decisions in our lives; but we have also relied on "rule of thumb" or "gut feeling" to make some other (even important) decisions. There is now empirical evidence suggesting that heuristics and gut feelings may not be poor "second best" methods for decision making. Rather they are flexible and effective decision-making processes formulated through life experience—which is to say, based on our interactions with the dynamic environment (Gigerenzer and Brighton 2009).

Furthermore, the individual decision maker can probably rationalize each choice he or she makes from his or her perspective, with a range of factors, including emotions, figured into that rationale. Utility is a rather broad concept that ultimately means happiness, which can incorporate emotions.

Considering all these, can we make a bold assertion that decision making is all about trying to optimize some kind of utility? Again, utility may mean different things to different people and in different contexts. Each person's utility function reflects individual experiences. And we may at times have difficulty formulating it because our experiences are qualitative and rich. Then examining the heterogeneity of human experience to understand how human agents value different things and make decisions can be theoretically enlightening, and also brings far more useful insight for policy than the notion of irrationality.

Much like the dual perspectives of decision theory, the representation of decision making in agent-based models falls into two general categories: optimization with a utility or objective function, and non-optimization. In the optimization category, there are variations of how agents in a model find solutions to their optimization problems. Some use mathematical programming (e.g., Berger 2001; Berger et al. 2006), which is optimization in the ultimate sense. Others often use approximation, and an approximate solution can be achieved by (1) using a genetic algorithm (e.g., Manson 2006) or more generally an evolutionary approach that makes adjustments based on experiences (e.g., the farmer household model in this study); or (2) sampling a limited solution space (e.g., Robinson and Brown 2009). When agents use these techniques to find an approximate solution to their optimization problems, the models are representing bounded rationality.

The representation of agents as non-optimizers reflects the psychological perspective. Non-optimizing agents often apply heuristic rules in decision making (e.g., Deadman et al. 2004; Kennedy et al. 2014). The psychological framework of belief, desire, and intention (BDI) has also been implemented to represent agent decision making in ABMs (e.g., Drogoul et al. 2016). A hybrid design of heuristics and utility calculation can be useful as well to simulate household-level decisions (e.g., Evans et al. 2011). Agent-based models may even employ cognitive architectures developed in artificial intelligence, such as SOAR and ACT-R, to represent agent decision making (Kennedy 2011).

In general, the representation of agent decision making in an agent-based model needs to be based on how people actually make decisions. The modeling purpose is also important for the choice of representation. Representations based on psychological and cognitive frameworks are thought to be more realistic than those based on optimization, and there is a general desire to enhance the cognitive aspects of agents (see Epstein 2014). However, with cognitive representations, like BDI, it can be difficult to understand what is going on in a model, and their usefulness for policy analysis is not obvious. Besides, the deep cognitive mechanisms underlying human decision making are not yet well understood. Heuristics, while useful for explaining existing patterns, may not be suitable for policy analysis because heuristic rules reflect what people do in immediate present and may change when situations change.

Optimization can be a useful representation of decision making for policy analysis, especially if we consider utility in a broader sense (with constraints) and may limit the ability of the agents to find perfect solutions in a model. Even implementing agents with perfect rationality could be appropriate for policy analysis. Schreinemachers and Berger (2006) argue that a representation of perfect rationality "seeks to identify inefficiencies not in the limited cognitive capacity of the human mind but in structural factors external to the decision maker, which may be addressed through policy intervention." Using mathematical programming to represent and solve optimization problems also allows modelers to include a large number of variables and constraints, capturing full agent heterogeneity (Schreinemachers and Berger 2006).

The PLR model can be used to illustrate the differences between heuristics and optimization. The households in the model could use the following heuristic rules: (1) if a member is older than age X, do farming; (2) if a male member is younger than age X, do migratory work with probability Y; (3) if a female member is younger than age X, do migratory work with probability Z; (4) if extra labor is available for farming, subcontract additional farmland; (5) if labor is insufficient for farming, rent out farmland. The model could still reproduce land use and livelihood patterns observed in three different villages by calibrating X, Y, and Z. But it would not, however, be so useful for exploring policy effects; the decisions of the agents would not even be sensitive to changes in wages or policy incentives.

Furthermore, the heuristic rules describe what agents do at the present time and may not be valid for exploring future scenarios unless we can make agents adapt their rules in the model. In contrast, income optimization represents the more fundamental principles of household decisions. The heuristic rules deducted based on our observations of agent behavior are manifestations of the fundamental decision principles in the current situation. Fundamental decision principles are more likely to remain the same than heuristic rules, and they may manifest as different choices and heuristics in different situations. Currently, the heuristic rules implemented in most agent-based models are fixed. John Holland's classifier system, which allows adaptation and creation of new rules, could be further explored to make truly adaptive agents.

Appropriate Level of Abstraction

Agent-based modelers must consider many elements in a real system when designing an ABM. It can therefore be difficult to decide what details to include (or exclude) in the model, and determining the appropriate level of abstraction has been a persistent challenge for the ABM community (Parker et al. 2003). Agent-based models can exhibit a gradient of abstraction levels, ranging from extremely abstract to extremely realistic representations. Schelling's (1971) segregation model, Axelrod's models on culture dissemination and cooperation (1997a, b), and Epstein and Axtell's Sugarscape model (1996) are classic abstract models that bring profound insights about social dynamics. As an example of extremely realistic design, An et al.'s model (2005) represents every household in the Wolong National Nature Reserve, plus a full range of demographic and economic dynamics, to examine the influence of human activities on the giant panda habitat. Because of its realism, the authors are able to interpret and compare their modeling results with other models in absolute quantitative terms, whereas most agent-based models look at trends or patterns, and discuss results in relative terms.

Note that as the level of details increases in an ABM, the model's ability to make general inferences decreases. One argument made against agent-based modeling is that it is intractable; more details make it even more difficult to understand model outcomes (Axtell and Epstein 1994). In addition, agent-based models can be overly fitting, i.e., fit too well to the specific system (Brown et al. 2005).

The increasing power of computers and big data present opportunities for more “realism” of agent-based models. Large, realistic models can be useful and are necessary in some cases, especially for applied studies, but we need to keep in mind that realism is not always equivalent to usefulness (see also Paola and Leeder 2011). “In searching for powerful models, this temptation to inclusiveness should be rested,” wrote Holland (2012). “A model’s clarity and generality directly depend on how much detail has been set aside.”

Large, realistic models can also increase the chance for errors and exacerbate the modeling issues discussed previously. Steve Bankes (1993) offers a fantastic fictional account of building, for a fictional Joint Chiefs of Staff, the ultimate combat simulation; as increasing details are demanded, and added to the model, it becomes quite useless at the end. Models are useful because they are abstractions of the real world, just as maps are useful because they simplify geography. In his book *Dreamtigers*, Jorge Luis Borges tells the ironic story of how cartographers driven by the “rigor of science” to create maps of increasing precision:

> “In that Empire, the Art of Cartography attained such Perfection that the map of a single Province occupied the entirety of a City, and the map of the Empire, the entirety of a Province. In time, those Unconscionable Maps no longer satisfied, and the Cartographers Guilds struck a Map of the Empire whose size was that of the Empire, and which coincided point for point with it. The following Generations, who were not so fond of the Study of Cartography as their Forebears had been, saw that that vast Map was Useless, and not without some Pitilessness was it, that they delivered it up to the Inclemencies of Sun and Winters. In the Deserts of the West, still today, there are Tattered Ruins of that Map, inhabited by Animals and Beggars; in all the Land there is no other Relic of the Disciplines of Geography.”

The appropriate level of detail is largely determined by the research question a model is intended to address (see also An et al. 2014); different questions about the same system may require different model designs. Let us use modeling the brain and the mind as an illustrative example. The human brain is an extremely complex system comprising billions of neurons and numerous physical, chemical, and biological processes that somehow give rise to higher-level cognitive functions and human intelligence (Baars and Gage 2010). Assume that our modeling goal is to explore how the brain gives rise to the mind. At the crudest level, a simple model of the left-right brain can bring us some understanding of human cognition. When we differentiate the frontal lobe, parietal lobe, temporal lobe, the occipital lobe, etc. in the model, we can understand more of the brain’s functions. However, this model is not yet sufficient to explain how the brain gives rise to the mind. To understand the brain-mind relation, it is probably necessary to include neurons and neuron networks in the model. But since neurons are supported by many chemical processes, should those also be represented? My thinking is no. Humans and other animals share similar chemical processes, and therefore these processes are probably not critical for explaining human intelligence.

Let's suppose now we have developed a model that simulates how neurons form networks through learning mechanisms, and that this is the process that gives rise to human intelligence. Even so, can this model explain cognitive problems, such as autism and Alzheimer's disease? I do not think so, for these disorders involve important physical, chemical, and biological processes that are not included in this model.

A good agent-based model captures a system's key elements and dynamics, with a level of detail that is sufficient to address the research question. Modeling is not only a technique—it is an art. The art is to capture the essence of a system, as a painter captures the spirit of the subject with a few strokes. The modeler, like the artist, must decide what details to include and how to capture them. Yes, there are painters who include such fine detail that we get lost in the intricacies. There are also painters in whose few strokes we can barely recognize the subject. Modeling is useful if we do it right. After all, there are the impressionist masters, but none of them painted solely from imagination—they all made intense observations of reality.

7.2.3 Strengthen a Model's Credibility

Conceptualization, based on a good understanding of the system in question, is the first step toward building a credible model for policy analysis. Several techniques can help us test and enhance a model's credibility: validation, sensitivity analysis, and robustness analysis.

Validation

We can address model validations on three levels: the conceptual, micro, and macro (Robinson 1997). Conceptual validation involves capturing the right processes and dynamics in a model. Empirical research and theory can provide insight into the processes and dynamics of the real system and are part of the conceptual validation. On the micro level, empirical data is useful for initializing model parameters and populating agents (Brown et al. 2008). At the macro level, comparing the simulated patterns with observed patterns, either qualitatively or quantitatively, constitute a formal validation (Axtell and Epstein 1994). A model could implement different mechanisms that all lead to the same macro-level pattern; the likelihood that the model captures the right mechanism is increased, and its credibility strengthened, if a model can reproduce multiple observed patterns (Grimm et al. 2005).

Validation at three levels gives a model increasing credibility; and the levels at which we confirm validation affect what we can claim from the model's experiments. Also different modeling purposes may require different levels of validation. To further illuminate the issue of model validation, it is helpful to quote John Holland about modeling (personal comm.):

> "I think of the model as a kind of axiom system. First, I try to make the basis of the model (the axioms) as clear as possible. I actually try to write an explicit list of assumptions. Then I try to make sure that the construction adheres to just these assumptions and no others. This is hard, but possible. The whole purpose of setting up axioms is to move all questions of interpretation to them. From that point onward, the rules of deduction, or the program, are a "mechanical" working out of consequences, with no interpretation involved in that part (unlike arguments of rhetoric and persuasion). That is what, in my mind, separates the scientific method from other methods (say, philosophical argument). In short, when the 'axiomatic' approach can be followed, the art and interpretative cleverness are concentrated in selecting the axioms. Then consequences are 'proved' without resort to interpretation. Note, however, that intuition usually guides us in what consequences we would LIKE to show. But you cannot 'cheat' the deductive method—the consequences may, or may not, follow from the axioms chosen."

Let's build upon Holland's "axiom systems." We may think in general that there are three types of agent-based models. In the first, not much is known about the system's processes, and the modeling purpose is to explain the mechanisms underlying macro patterns. In this case, the modeler can list any axioms, including any assumptions about the mechanisms. The modeler may even choose to "manipulate" the axioms. As long as the model reproduces the observed patterns, the modeler can claim that the postulated mechanism is plausible. Even such plausible mechanisms are useful and can guide the direction of empirical studies. Craig Reynolds's bird flocking model (Boid) and Holland's language model, which explores how grammar emerges and how languages evolve, fall into this category. I would think these models are so-called "existence proof models."

A second type of model is used to explore and test abstract ideas. The modeler assumes or has some intuition that a system works in a certain way and seeks to "prove" that assumption, using a model capable of reproducing some stylistic patterns. The modeling purpose, however, is not to prove the assumption or intuition but to illustrate further insight about the system. In this case, it is appropriate to list all the assumptions as axioms and then let the program work out. My simple model on Towns, Cities, and the Happiness of Humanity (see personal.umich.edu/~qtian/HappinessOfHumanity.htm), and some of the early exploratory agent-based models, such as Robert Axelrod's (1997a) culture dissemination model fall into this category. I tend to think that such models are more about brain exercise, and attempt to illustrate some insight.

The third type of model is used for prediction (e.g., An et al. 2005) or, as in this study, has clear policy implications. For these models, validation at all three levels is essential to achieve sufficient credibility to persuade policy-makers. In other words, the axioms must largely reflect facts. This is close to Steve Bankes's (1993) notion of "consolidative models." Bankes (1993) offers an interesting discussion on the important role of "exploratory models" for policy analysis. However, even the exploratory capability of a model need to rely on certain levels of understanding about a system to be useful for policy analysis. In implementing agent-based models, we almost always make some assumptions, but the more our axioms rely on assumptions rather than fact, the less credible will be our inferences from the model experiments. There are also technical issues associated with using too many assumptions I will discuss later.

These three model types are intended for different purposes, and the validation levels required for them differ as well. To make agent-based modeling a rigorous research method, we should be clear about the modeling purpose and our assumptions, just as mathematicians explicitly list their axioms. We should also discuss how the assumptions may affect our conclusions. For important assumptions, it may be necessary to do additional experiments to examine their potential impacts on model outcomes. Two analytical tools especially useful for analyzing axioms are sensitivity analysis and robustness analysis.

Sensitivity Analysis

Sensitivity analysis tests how changes in a model's parameters or variables can affect outcomes (Railsback and Grimm 2011). We can apply sensitivity analysis when we lack reliable or accurate estimates about a model parameter or variable. If the results are sensitive to small changes in a model parameter or variable, we need to collect additional data to improve the estimates. Sensitivity analysis can also be used for model verification and validation (e.g., An et al. 2005). We can vary the parameter or variable values to explore how this affects outcome variables. If the patterns of change do not conform to our expectations (based on our theoretical understanding or empirical work), we need to examine model design and implementation to make sure the computer code is correct and the conceptual model is "right."

Scenarios that combine extreme values of parameters or variables are particularly useful because it is relatively easy to discern how the simulated system should behave under them. As the numbers of parameters and variables increase, it can quickly grow burdensome to conduct systematic model experiments using all possible combinations; sensitive parameters or variables identified by sensitivity analysis can help narrow the range of possible scenarios (e.g., Happe et al. 2006).

Sensitive parameters or variables can be useful for policy interventions. For example, An et al. (2005) identify several variables to which household electricity consumption and, consequently, panda habitat in the Wolong National Nature Reserve, are sensitive. Among them, the age at which people marry and the price for electricity could help formulate policy interventions for habitat conservation. The PLR model shows that in villages with average farmland, the decisions of households to rent out farmland are sensitive to the size of the rental subsidy. This insight could be used by policy-makers to choose a subsidy amount, for example, one that influences land rental markets cost effectively, or one that allows for farmland concentration synchronized with rural labor transfer to the urban sector.

Robustness Analysis

Robustness analysis tests how a specific component of a model's implementation affects model outcomes. For example, we can test alternative representations of agent decision making or alternative distributions of agent attributes. We can explore the distribution of an outcome variable to understand the uncertainty of model outcomes if we know the distribution of a parameter or variable. Every assumption is theoretically subject to robustness analysis. In practice, however, it is impossible to test every one because agent-based models usually make a great many assumptions.

We should at least try to examine the major assumptions. If the model still produces the same outcomes with alternative implementations, the model results are robust and the assumptions are not problematic. Otherwise, we would need to do additional research to learn more about the real system. Despite all the effort made to understand rural development in the PLR through empirical research, there are still some unknown elements in the system. The robustness tests against two major assumptions—that current grain subsidies are based on actual areas planted for rice, and that all farmland rental contracts involve payments—do not only enhance credibility of the model but also improve our understanding of policy effects.

We can also use robustness analysis as an analytical tool to understand our creations. What is the specific contribution of a given component to model outcomes? What is the relative importance of a model's major components? We can remove a component from a model to understand its contribution to model outcomes. This allows us to look into the black box and unravel the inner workings of an agent-based model, and helps us explain why a model behaves in a certain way or produces certain outcomes. Such explanation also helps us to communicate with non-ABM modelers and convince policy-makers.

These analysis results may be used to simplify a model as well. The Einstein principle is a good guideline for modeling: Models should be made as simple as possible, but not simpler. Robustness analysis is a useful technique to find that "right" model by teasing out relevant but unimportant components. For example, social relations in the farmer household model are relevant to the negotiation of farmland contracts and make the model appear more realistic. But they carry little weight for model outcomes, and the model could be simpler without them. In fact, a parallel model implemented in Python without social relations produces the same dynamics and results.

7.2.4 Models as Projection Systems

Holland's notion of models as axiom systems is very useful; we may further think of all models as *projection systems* from some elements to outcomes. Mathematicians start with axioms (elements) and use logical deduction rules (the projection system) to infer system behavior. For regression models, and mathematical model more generally, the elements are state variables, and the project system is a formula; to define a mathematical model, the modeler needs to choose the form of the formula and the variables.

For agent-based models, the elements are many and diverse, including agent attributes, agent decision making, the attributes and dynamics of the environment, interactions, feedback, and often some stochastics. The computer program that weaves all these elements together is the projection system. The modeler must decide which elements in the real system to include and how to relate these elements to one another in the model, necessarily making numerous assumptions. The projection system is thus not as straightforward as a mathematical formula or as clean as deduction rules. From this perspective, we can see more clearly why the benefit of using an agent-based model to represent micro-level processes also creates challenges for its modeler.

On the other hand, as projection systems, agent-based models are not so different from other types of models. In fact, an agent-based model can be approximated by a mathematical model (most likely nonlinear) that directly relates model parameters and variables to model outcomes, ignoring agents and their actions and interactions (e.g., Happe et al. 2006). For all model types, model outcomes depend on nothing more than the elements we select and the projection system we use. How much truth we attach to axioms, model elements, and mechanisms affects our confidence in the model and what we can claim from modeling results.

We know that for mathematical models, and for regression models in particular, more variables increase fitness—but the fittest model may not be the most useful. We know that higher orders of mathematical formula generally lead to better fit to data—but the model's prediction ability may decrease, as shown by Gigerenzer and Brighton (2009). Similarly, more details in agent-based models do not necessarily improve the model, and too many details can make a model lose generality and become less useful for explaining other systems, or make it problematic for predicting future scenarios; those relevant but inessential details can vary among similar systems or easily change in the future. Again, robustness analysis is helpful for finding the "right" agent-based model just as step-wise techniques are useful for finding the "right" regression model.

Modeling is essentially about exploring the unknowns of a system based on what we know—we build a model based on what we know to learn new things about a system. The model's ability to bring new understanding therefore rests on what we know. With agent-based modeling, we can gain new understanding by exploring scenarios, and we can do experiments to explore plausible scenarios. But when too little is known about the real system, the number of scenarios we must test grows exponentially from our assumptions. Systematic model experiments will be overwhelming, and even techniques like sensitivity analysis and robust analysis can become ineffective.

To model for policy analysis, then, it is essential to learn as much as possible about a system. This helps us to ask meaningful questions about the system and provides insight about how to design alternative policies to influence the system. This is important for model conceptualization and validation, and can also mitigate the practical issue of experiment analysis just described.

7.2.5 Unlock the Modeling Potential for Policy Analysis

Agent-based modeling is useful for evaluating policy effects, but we can take it further, using models to explore policy levers, tipping points, adaptive policy, robust policy, unintended consequences, and disastrous future outcomes. Agent-based models are particularly powerful for addressing *what if* questions. Goolsby and Cioffi-Revilla (2011) raise many great *what if* questions about development and disaster response in sub-Saharan Africa, where social conflicts, unstable governments, and climate all contribute to low levels of development and human well-being.

Models are excellent adjuncts to human intellect, and we can combine models and human intellect to better inform policy decisions (Lempert 2003). Humans have an incredible ability to recognize patterns and make inferences with limited information. We also possess contextual and qualitative knowledge that is difficult to implement in a model. A computer cannot capture the richness of human experience but is capable of computing a large number of scenarios. If we offer policy-makers the modeling results about the performance of multiple policy options, rather than just one, across many scenarios, it will allow policy-makers to integrate their unique human capabilities and other sources of information as they consider policy choices. In this study, for example, the model provides insights into the effects of different subsidies on rural development at different stages of development across multiple outcome variables. This gives policy-makers flexibility to consider and choose appropriate options and use contextual information, such as generational changes—which are not represented in the model but play an important role in influencing the success of subsidies to large farms—under a variety of scenarios.

We can combine agent-based modeling with other methods to enhance its capabilities for policy analysis (see also O'Sullivan et al. 2016). For example, we can combine mathematical tools developed in systems dynamics (LaSalle and Lefschetz 1961; Martynyuk 1998; Bramson 2009, 2010) and bring in data-mining techniques, such as evolutionary algorithms, to explore the model parameter space and data produced by agent-based models (e.g., Miller 1998). This can help identify conditions that lead to disastrous outcomes, generate insights about robust policy, and inform adaptive policymaking. We can integrate GIS within an agent-based model to explore spatial effects (see Torrens 2010; Heppenstall et al. 2012; Malanson and Walsh 2015). Geospatial agent-based models are particularly useful for disaster evacuation and rescue planning (e.g., Crooks and Wise 2013; Crooks et al. 2015). We can also integrate social network analysis (see Wasserman and Faust 1994; Barabási 2002; Newman et al. 2006) with agent-based models to explore social influences (e.g., Andrei et al. 2014). Real social network data are often difficult to collect, and modeling can help explore situations associated with incomplete information or uncertainty.

Social network analysis, as another technique for analyzing complex systems, brings unique insights about policy interventions. Social network-based principles have long been used to effect change in the real world. Such interventions may aim to control or accelerate the diffusion process in social networks (e.g., to contain contagious disease, promote innovation), stabilize or destroy system structure (e.g., enhance stability of electrical grids, eliminate criminal or terrorist networks), or improve system performance (e.g., increase voting participation, improve organization efficiency). Social network-based interventions can target nodes, links, groups, or the overall network structure to influence system-level outcomes (see Valente 2012). Social network analysis is an area where the complexity approach has been relatively successful in influencing policy, particularly in epidemiology.

Social network analysis and social network-based interventions are large topics, beyond the scope of this book. The point here is that social interactions could be policy levers for influencing individual behavior to curb negative outcomes or foster positive changes (e.g., Centola 2010; Rand et al. 2011; Bond et al. 2012). Social network-based interventions are therefore an important part of "smart" policy. As social media and smart devices become more popular, social networks in the cyberspace will likely exert increasing influence over individual behavior and could be used for policy purpose. To make "smart" use of social media for policy interventions, again, we need to understand how these virtual relationships affect individual behavior in the first place.

7.3 An Unfolding End

Agent-based modeling has become increasingly popular in a growing number of fields to simulate various systems, but advances in the theoretical understanding of complex adaptive systems are slow. According to Murray Gell-Man and late John Holland, the founding fathers of CAS, these systems are difficult to study and we are only just beginning to understand them.

I have no doubts that the science of complexity is the science of the twenty-first century, as Stephen Hawking says. But I think it may be helpful if we shift away from the broader notion of complexity and instead focus on some of the specific properties of complex systems and emphasize the CAS approach to examine the micro-level processes. (The very notion of complexity, to some skeptics, indicates something that is unknowable, contributing to suspicions about the science of complexity).

Sustainability is a common property of many complex adaptive systems, from social organizations to economic systems and human civilizations, and can be an organizing concept for studying CAS more generally. These systems all "grow" in some way. And it is generally desirable for them to exhibit resilience. However, they also seem to share a common cycle of fast growth, stagnancy, decay, and collapse. It appears that growth and resilience are somehow intertwined, and even at odds with each other at times.

We can characterize the sustainability of complex adaptive systems in terms of growth and resilience, and define it as continuous, resilient growth. Investigating the fundamental mechanisms underlying sustainability will expand and deepen our general understanding of complex adaptive systems, and also bring profound insight for how policy can foster changes to promote growth and enhance resilience in such systems. I believe that niches, which interested John Holland in his late life (see Holland 2012, 2014), play a large role in such mechanisms. And I can envision how niches are responsible for those common evolutionary patterns in complex adaptive systems—but this is for future research.

Thus, my inquiry about the sustainability of coupled human-environment systems, which started a decade ago, has arrived at this point, an unending end. Our quest for understanding human-environment systems, and complex adaptive systems more generally, will continue to unfold and expand. It is in that quest, that examination of the deep unknown, that one discovers the purpose and the joy behind all scientific inquiry.

References

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

An, L., Zvoleff, A., Liu, J., & Axinn, W. (2014). Agent-based modeling in coupled human and natural systems (CHANS): Lessons from a comparative analysis. *Annals of the Association of American Geographers, 104*(4), 723–745.

Andrei, A., Comer, K., & Koehler, M. (2014). An agent-based model of network effects on tax compliance and evasion. *Journal of Economic Psychology, 40*, 119–133.

Axelrod, R. (1997a). The dissemination of culture a model with local convergence and global polarization. *Journal of Conflict Resolution, 41*(2), 203–226.

Axelrod, R. M. (1997b). *The complexity of cooperation: Agent-based models of competition and collaboration*. Princeton: Princeton University Press.

Axtell, R. L., & Epstein, J. M. (1994). Agent-based modeling: Understanding our creations. *The Bulletin of the Santa Fe Institute, 9*(2), 28–32.

Baars, B. J., & Gage, N. M. (2010). *Cognition, brain, and consciousness: Introduction to cognitive neuroscience*. Burlington: Academic.

Bankes, S. (1993). Exploratory modeling for policy analysis. *Operations Research, 41*(3), 435–449.

Barabási, A.-L. (2002). *Linked: The new science of networks*. Cambridge: Perseus Publishing.

Becker, G. S., & Murphy, K. M. (2009). *Social economics: Market behavior in a social environment*. Cambridge: Harvard University Press.

Berg, J., Dickhaut, J., & McCabe, K. (1995). Trust, reciprocity, and social history. *Games and Economic Behavior, 10*(1), 122–142.

Berger, T. (2001). Agent-based spatial models applied to agriculture: A simulation tool for technology diffusion, resource use changes and policy analysis. *Agricultural Economics, 25*(2–3), 245–260.

Berger, T., Schreinemachers, P., & Woelcke, J. (2006). Multi-agent simulation for the targeting of development policies in less-favored areas. *Agricultural Systems, 88*(1), 28–43.

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (1994). *At risk: Natural hazards, people's vulnerability and disasters*. London: Routledge.

Bond, R. M., Fariss, C. J., Jones, J. J., Kramer, A. D., Marlow, C., Settle, J. E., & Fowler, J. H. (2012). A 61-million-person experiment in social influence and political mobilization. *Nature, 489*(7415), 295–298.

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

Bramson, A. L. (2010). *Formal measures of dynamical properties: Robustness and sustainability* (AAAI Technical Report FS-10(3), pp. 16–25).
Brown, D. G., Page, S., Riolo, R., Zellner, M., & Rand, W. (2005). Path dependence and the validation of agent-based spatial models of land use. *International Journal of Geographical Information Science, 19*(2), 153–174.
Brown, D. G., Robinson, D. T., An, L., Nassauer, J. I., Zellner, M., Rand, W., et al. (2008). Exurbia from the bottom-up: Confronting empirical challenges to characterizing a complex system. *Geoforum, 39*(2), 805–818.
Castella, J. C., Trung, T. N., & Boissau, S. (2005). Participatory simulation of land-use changes in the northern mountains of Vietnam: The combined use of an agent-based model, a role-playing game, and a geographic information system. *Ecology and Society, 10*(1), 27.
Centola, D. (2010). The spread of behavior in an online social network experiment. *Science, 329*(5996), 1194–1197.
Cioffi-Revilla, C. (2014). Computation and social science. In *Introduction to computational social science* (pp. 23–66). London: Springer.
Cioffi-Revilla, C., & Goolsby, R. (2011, September). Advanced modeling capability for rapid disaster response'. *Innovation Beyond Imagination, 7*, 12–13.
Cotla, C. R. (2016). Heterogeneous preferences and the dynamics of cooperation in networked societies: A dialogue between experimental and computational approaches. PhD dissertation.
Crooks, A. T., & Wise, S. (2013). GIS and agent-based models for humanitarian assistance. *Computers, Environment and Urban Systems, 41*, 100–111.
Crooks, A. T., Croitoru, A., Lu, X., Wise, S., Irvine, J., & Stefanidis, A. (2015). Walk this way: Improving pedestrian agent-based models through scene activity analysis. *ISPRS International Journal of Geo-Information, 4*(3), 1627–1656.
Deadman, P., Robinson, D., Moran, E., & Brondizio, E. (2004). Colonist household decision making and land-use change in the Amazon Rainforest: An agent-based simulation. *Environment and Planning B: Planning and Design, 31*(5), 693–709.
Drogoul, A., Huynh, N. Q., & Truong, Q. C. (2016). Coupling environmental, social and economic models to understand land-use change dynamics in the Mekong Delta. *Frontiers in Environmental Science, 4*, 19.
Epstein, J. M. (2014). *Agent_Zero: Toward neurocognitive foundations for generative social science*. Princeton: Princeton University Press.
Epstein, J. M., & Axtell, R. (1996). *Growing artificial societies: Social science from the bottom up*. Washington, DC: Brookings Institution Press.
Evans, T. P., Phanvilay, K., Fox, J., & Vogler, J. (2011). An agent-based model of agricultural innovation, land-cover change and household inequality: The transition from swidden cultivation to rubber plantations in Laos PDR. *Journal of Land Use Science, 6*(2–3), 151–173.
Farmer, J. D., & Foley, D. (2009). The economy needs agent-based modelling. *Nature, 460*(7256), 685–686.
Gigerenzer, G., & Brighton, H. (2009). Homo heuristicus: Why biased minds make better inferences. *Topics in Cognitive Science, 1*, 107–143.
Gilbert, G. N. (2007). *Agent-based models* (Vol. 153). Thousand Oaks: Sage.
Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W. M., Railsback, S. F., et al. (2005). Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science, 310*(5750), 987–991.
Happe, K., Kellermann, K., & Balmann, A. (2006). Agent-based analysis of agricultural policies: An illustration of the agricultural policy simulator AgriPoliS, its adaptation and behavior. *Ecology and Society, 11*(1), 49.
Heppenstall, A. J., Crooks, A. T., See, L. M., & Batty, M. (Eds.). (2012). *Agent-based models of geographical systems* (pp. 739–748). New York: Springer.
Hogarth, R. M., & Reder, M. W. (1987). *Rational choice: The contrast between economics and psychology*. Chicago: University of Chicago Press.
Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. Cambridge: Perseus Books.

Holland, J. H. (1998). *Emergence: From chaos to order*. Cambridge: Perseus Books.

Holland, J. H. (2012). *Signals and boundaries: Building blocks for complex adaptive systems*. Cambridge: MIT Press.

Holland, J. H. (2014). *Complexity: A very short introduction*. Oxford: Oxford University Press.

Houser, D., Xiao, E., McCabe, K., & Smith, V. (2008). When punishment fails: Research on sanctions, intentions and non-cooperation. *Games and Economic Behavior, 62*(2), 509–532.

Jacob, J. (1961). *The death and life of great American cities*. New York: Vintage Books.

Janssen, M. A., & Ostrom, E. (2006). Empirically based, agent-based models. *Ecology and Society, 11*(2), 37.

Kennedy, W. G. (2011). Modelling human behavior in agent-based models. In M. Batty, A. Heppenstall, & A. Crooks (Eds.), *Agent-based models of geographical systems, Part 2* (pp. 167–179). New York: Springer.

Kennedy, W. G., Cotla, C. R., Gulden, T. R., Coletti, M., & Cioffi-Revilla, C. (2014). Towards validating a model of households and societies of East Africa. In S. H. Chen, I. Terano, H. Yamamoto, & C. C. Tai (Eds.), *Advances in computational social science: The fourth world congress* (pp. 315–328). New York: Springer.

Kurzban, R., & Houser, D. (2005). Experiments investigating cooperative types in humans: A complement to evolutionary theory and simulations. *Proceedings of the National Academy of Sciences of the United States of America, 102*(5), 1803–1807.

LaSalle, J. P., & Lefschetz, S. (1961). *Stability by Liapunov's direct method with applications*. New York: Academic Press.

Lempert, R. (2002). Agent-based modeling as organizational and public policy simulators. *Proceedings of the National Academy of Sciences, 99*(Suppl. 3), 7195–7196.

Lempert, R. J. (2003). *Shaping the next one hundred years: New methods for quantitative, long-term policy analysis*. Santa Monica: Rand Corporation.

Malanson, G. P., & Walsh, S. J. (2015). Agent-based models: Individuals interacting in space. *Applied Geography, 56*, 95–98.

Manson, S. (2006). Land use in the southern Yucatán peninsular region of Mexico: Scenarios of population and institutional change. *Computers, Environment and Urban Systems, 30*(3), 230–253.

Manson, S. M., & Evans, T. (2007). Agent-based modeling of deforestation in southern Yucatan, Mexico, and reforestation in the Midwest United States. *Proceedings of the National Academy of Sciences, 104*(52), 20678–20683.

Martynyuk, A. A. (1998). *Stability by Liapunov's matrix function method with applications*. New York: CRC Press.

Miller, J. H. (1998). Active nonlinear tests (ANTs) of complex simulation models. *Management Science, 44*(6), 820–830.

Miller, J. H., & Page, S. E. (2007). *Complex adaptive systems: An introduction to computational models of social life*. Princeton: Princeton University Press.

Mitchell, M. (1992). *Complexity: A guided tour*. New York: Oxford University Press.

Newman, M. E. J., Barabási, A.-L., & Watts, D. J. (2006). *The structure and dynamics of networks*. Princeton: Princeton University Press.

O'Sullivan, D., Evans, T., Manson, S., Metcalf, S., Ligmann-Zielinska, A., & Bone, C. (2016). Strategic directions for agent-based modeling: Avoiding the YAAWN syndrome. *Journal of Land Use Science, 11*(2), 177–187.

Organization for Economic Co-operation and Development (OECD) Global Science Forum. (2009). *Report on applications of complexity science for public policy: New tools for finding unanticipated consequences and unrealized opportunities*. Retrieved from https://www.oecd.org/science/sci-tech/43891980.pdf

Paola, C., & Leeder, M. (2011). Environmental dynamics: Simplicity versus complexity. *Nature, 469*(7328), 38–39.

Parker, D. C., Manson, S. M., Janssen, M. A., Hoffman, M. J., & 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*, 314–337.

Railsback, S. F., & Grimm, V. (2011). *Agent-based and individual-based modeling: A practical introduction*. Princeton: Princeton University Press.
Rand, D. G., Arbesman, S., & Christakis, N. A. (2011). Dynamic social networks promote cooperation in experiments with humans. *Proceedings of the National Academy of Sciences, 108*(48), 19193–19198.
Robinson, S. (1997). Simulation model verification and validation: Increasing the users' confidence. In *Proceedings of the 29th Conference on Winter Simulation* (pp. 53–59). IEEE Computer Society.
Robinson, D. T., & Brown, D. G. (2009). Evaluating the effects of land-use development policies on ex-urban forest cover: An integrated agent-based GIS approach. *International Journal of Geographical Information Science, 23*(9), 1211–1232.
Robinson, D. T., Brown, D. G., Parker, D. C., Schreinemachers, P., Janssen, M. A., Huigen, M., et al. (2007). Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science, 2*(1), 31–55.
Schelling, T. C. (1971). Dynamic models of segregation†. *Journal of Mathematical Sociology, 1*(2), 143–186.
Schreinemachers, P., & Berger, T. (2006). Land use decisions in developing countries and their representation in multi-agent systems. *Journal of Land Use Science, 1*(1), 29–44.
Scott, J. C. (1977). *The moral economy of the peasant: Rebellion and subsistence in Southeast Asia*. New Haven: Yale University Press.
Sen, A. (1981). *Poverty and famines: An essay on entitlement and deprivation*. Oxford: Oxford University Press.
Simon, H. A. (1956). Rational choice, and the structure of the environment. *Psychological Review, 63*, 129–138.
Smith, V. L. (2005). *Bargaining and market behavior: Essays in experimental economics*. Cambridge: Cambridge University Press.
Strauss, J., & Thomas, D. (1995). Human resources: Empirical modeling of household and family decisions. In J. Behrman & T. N. Srinivasan (Eds.), *Handbook of development economics* (Vol. 3, pp. 1885–2023). Amsterdam: North Holland.
Susan, E. (1977). *The poverty of revolution: The state and the urban poor in Mexico*. Princeton: Princeton University Press.
Torrens, P. M. (2010). Agent-based models and the spatial sciences. *Geography Compass, 4*(5), 428–448.
Tversky, A., & Kahneman, D. (1975). Judgment under uncertainty: Heuristics and biases. In D. Wendt & C. Vlek (Eds.), *Utility, probability, and human decision making*. Dordrecht: Springer.
Valente, T. W. (2012). Network interventions. *Science, 337*(6090), 49–53.
Van Berkel, D. B., & Verburg, P. H. (2012). Combining exploratory scenarios and participatory backcasting: Using an agent-based model in participatory policy design for a multi-functional landscape. *Landscape Ecology, 27*(5), 641–658.
Walsh, S. J., & Mena, C. F. (2016). Interactions of social, terrestrial, and marine sub-systems in the Galapagos Islands, Ecuador. *Proceedings of the National Academy of Sciences, 113*(51), 14536–14543. doi:10.1073/pnas.1604990113.
Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge: Cambridge University Press.

Acknowledgments

This book is the outcome of a marriage between reality and the science of complexity. While Professor John Holland's work in complex adaptive systems inspired my thinking in the sustainability of human-environment systems, many farmers around Poyang Lake provided me a reality check. I found a match between the two following several visits to the area, especially after I'd spent a summer in the villages.

During my visits to the villages, many farmers took the time to talk to me and served me meals, sometimes simply because I happened to be visiting at lunchtime or dinnertime. Some offered me a place to stay, welcoming me as if I were family, and giving me the privilege of observing their private lives. They taught me many things beyond books. Professor Holland was also a constant source of encouragement for this work and contributed to some of the ideas implemented in the agent-based model. I'd like to dedicate this book to the farmers around Poyang Lake and to the memory of John Holland.

Many other people and organizations have contributed to this work. Without them, this marriage would likely have remained just a proposal. Especially, I'd like to thank my PhD advisor, Dr. Daniel Brown. This work started when I was studying at the University of Michigan. I was a research assistant and participated in his research project on land use and vulnerability around Poyang Lake. That project provided a broad space for me to explore my interests, eventually leading to my dissertation. The household surveys were carried out by the land-use project. All the data and social contacts accumulated through the land-use project were crucial to the success of this work.

Several local scientists at Jiangxi Normal University, including Prof. Lin Zheng, Dr. Shuhua Qi, Prof. Ying Liu, Dr. Dingguo Ma, Prof. Dunyin Wu, and Prof. Xiaobo Su, as well as Dr. Shuming Bao at the China Data Center in Michigan, provided data support for this work. They helped arrange my field trips and logistics in Nanchang. They offered useful input to the interview questions. Dr. Luguang Jiang at the Institute of Geographic Sciences and Natural Resources Research of the Chinese

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0

Academy of Sciences also provided important data, which included GIS data on levees. And I learned much about the Poyang Lake area from each of them.

Qiang Wang, a graduate student at Jiangxi Normal University back then, accompanied me to the villages in summer of 2008. Summers in Jiangxi are very hot and steamy. Just imagine walking in the fields under the sun or sleeping at night without air conditioners. He didn't mind all that. It was sort of fun to "storm" the small convenient stores run by some households in the villages for ice cream—as I think about it now. With his help, I was able to venture into rural areas I hadn't planned to visit and learn more about rural development in the region.

Drs. Maria Lemos, Rick Riolo, and Stephen Salant provided valuable guidance for my earlier dissertation work. Professor Robert Axelrod (my postdoctoral advisor), Professor James Olds and my colleagues in Computational Social Science at George Mason University also gave good comments. Aaron Bramson, a fellow PhD student at the Center for the Study of Complex Systems in Michigan, played a role in the "emergence" of the three-dimensional space of well-being. It was during a conversation with him about tipping points that the space of well-being "jumped" into my mind, and the sustainability framework took shape.

I'd also like to thank my parents who have given me everything I have. The early life experience they provided me found a way into this work, and they keep me in touch with what is happening in China. There are many more people who belong on this thank-you list, and I won't be able to write all their names here. But I do appreciate whatever you have done and remember you in my heart.

Major financial support for my earlier dissertation work was provided by the Graham Environmental Sustainability Institute Graduate Fellowship, a NASA Earth and Space Science Fellowship, and the Rackham Graduate School One-Term Dissertation Fellowship. A summer research fund from George Mason University allowed me to revisit the Poyang Lake area in 2014 and 2015. The recent field work informed the new work on agent-based modeling and policy analysis. The discussions in the book also reflect my thinking developed through my teaching at George Mason University, including a seminar on complex adaptive systems and policy. I appreciate very much the contributions from those students who participated in this seminar.

Finally, a special thanks goes to my editor, Zachary Romano. He reached out to me at the annual meeting of the American Association of Geographers in 2015 and has believed in me since then. He has also been extremely patient with an inexperienced author and an assistant professor who is sometimes overwhelmed by many challenges in her early academic career. Professor Hilton Root at the Schar School of Policy and Government provided me important mentoring in the process of publication. His work on complexity and dynamics among nations was also an inspiration. This book came into being, to a large extent, because of them.

About the Author

Qing Tian is an Assistant Professor of Computational Social Science in the College of Science at George Mason University, affiliated with the Center for Social Complexity at the Krasnow Institute for Advanced Study. She is an interdisciplinary researcher with interests in land use, development, and human-environment systems more generally. She applies complex adaptive systems theory and combines a range of empirical methods with computer modeling to analyze the complex processes and dynamics in human-environment systems. She is interested in policy analysis from the viewpoint of complex systems, and related to this, human cognition and decision making. Email: qtian2@gmu.edu. Website: mason.gmu.edu/~qtian2. Mailing address: Research Hall, Room 374, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA.

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0

Index

A
Abstraction level, agent-based model, 130–132
Adaptation mentality, 123
Adaptive capacity, 7
Adaptive interactions of agents, 1
Agent decision making, 8
Agent-based computational economics (ACE), 120
Agent-based model (ABM), 72, 124–138
  policy analysis
    challenge of conceptualization, 125–132
    design useful models, 124, 125
    model's credibility, 132–135
    projection systems and general modeling issues, 135, 136
    unlock, 137, 138
Agriculture, 15, 23
  flood impacts on, 62
ArcGIS, 34
Axiom systems, 133

B
Belief, desire, and intention (BDI), 129
Bird flocking model (Boid), 133
Building a new countryside program, 23, 24, 65
Business-oriented households, 57

C
China, broader development and policy context, 21–24
Climate impacts, rural areas, 113, 114
Complete return polder, 21
Complex adaptive systems (CAS), 1, 2
  sustainability of human-environment systems, 1–3
    adaptive interactions of agents, 1
    CHES, 2
    hierarchical structures, 2
    non-linearity, 1
    path-dependent, 2
    phase transition, 2
    self-organize, 2
Complex systems approach, 115, 116, 123
Cotton, 17
Coupled human-environment systems (CHES), 2–4, 8–10, 115
  natural system, 2
  resilience, 4
  sustainability, 3, 5
  well-being, 3, 6

D
Decision theory, 127–130
Digital elevation models (DEMs), 17, 30
Diversity of places, 116

E
Economic growth, 118
Economic shocks, 106, 110
  exploring effects, 96, 97
  resilience, 72, 96–102, 105
  rural development, 97–100, 102
Empirical research methods, 126, 127

Q. Tian, *Rural Sustainability*, SpringerBriefs in Geography,
DOI 10.1007/978-3-319-52685-0

Environmental shocks, plausible economic and, 72
Exposure, 3, 4, 6, 7, 10, 32, 34
  concepts, 5
  definitions, 4
  flood hazards, 10
  to flooding, 45
  measures, 5, 8, 34
  and sensitivity, 4
  spatial variations, 8
Extreme-income households, 58

F
Farmer household agents, 76
Farmer household model, 125, 129
Farming-based livelihood profile, 57
Flood, 31, 35, 41
  experiences, 61
  hazard zone, 29, 31, 32, 35, 39
  impact mitigation, 66, 67
  impacts on agriculture, 62
  mitigation, 40, 112
  risk, mapping, 29–31
Free-market economy, 60

G
Global constraints, 116
Global economy, 119
Global sustainability, 116
Grain Bag Responsibility System, 22

H
High flood hazard zone, 32, 35, 40
High-income households, 54, 56–58
Household agents, 73, 80, 84, 85, 90–92, 97, 99, 100, 104
  decision making
    steps, 83, 84
  endowments and attributes, 77
  farmer, 76
Household Responsibility System, 22
Hukou, 24, 63, 67, 109
Hukou reform, 111
Hukou registration system, 61
Human capital, 59
Human well-being, 39, 40
Human-environment system, 1–3, 15, 17, 19–21

I
Industrial sector, 111

J
Jiangxi Statistical Yearbook, 15

L
Land rental market, 76, 78
Land rental relationships, 74
Land use, 40
Land-use land-cover map, 34
Leadership, 52
Lewis's theory of unlimited supply of labor, 22
Local constraints, 116
Local sustainability, 116
Low-income households, 53, 54

M
Men Lu, 57
Migrant workers, 58, 60
Migration policy, 64, 95
Migratory work, household agent's, 78
Millennium Development Goal (MDG), 35
Multiplier effect, 119

N
Niches, 139
Nonfarm income, 67
NumHouseholdTrade, 76

O
"One-season" rice, 17

P
Partial return polder, 21
Polders, 20, 21
Policy analysis, 124–138
  agent-based model
    challenge of conceptualization, 125–132
    design useful models, 124, 125
    model's credibility, 132–135
    projection systems and general modeling issues, 135, 136
    unlock, 137, 138
  complex systems approach, 123
Policy context in China, 21–24
Poor farmland, 110
Poor households, 59, 65
Poverty reduction programs, 67
Poyang Lake Region (PLR), China
  agricultural activities, 18
  assessment results, 35, 38, 39

dynamic human-environment system, 15, 17, 19–21
elevations, 31
empirical data, 74, 76, 83, 104
entities, interactions, and feedbacks, 72–74
farmer households, 60
flood hazard zone, 10, 35
flood risk, mapping, 29–32
future development and policy interventions, 39–41
Landsat Thematic Mapper (TM), 30, 34
land-use land-cover map, 34
limitation of model, 104, 105
mapped patterns, 37
measuring well-being, 31, 32, 34–36
model design and implementation, 76
  farmer household agents, 76
  land rental market, 76, 78
  migratory work efficiency function, 78
  model parameters and model initialization, 80–82
  rice yield functions, 79
model verification and validation, 80, 83, 134
plausible economic and environmental shocks and resilience, 72
resilience of rural development
  amid social and environmental changes, 102, 103, 105
  economic shocks, 96–100, 102
  potential effects of severe floods, 95, 96
robustness analysis, 104
rural development, 10
rural livelihoods, 51, 67
subsidy policies, 71, 72
  experiments for exploring, 83, 84
  to large farms, 83, 84, 90, 91, 93–95, 105
  poor, average and good farmland resources, 85–88, 90–92
  to rental contracts, 91, 92, 105
  to rice growers, 83, 90–92, 94–96, 105, 106, 112
  villages and adaptive policy, 92–95
sustainable development
  findings from study, 109, 110
  framework for analyzing global sustainability, 116–120
  future development and policy recommendations, 111–113
  implications, 113–115
  vulnerability to sustainability, 115
terrain, 17
townships
  classification, 38
  distribution, 39
Prisoner's Dilemma, 9
Projection systems, 135, 136

R
Rational choice theory, 128
Remote sensing, 41
Residency registration system, 64
Resilience, 4, 6, 7, 9, 11, 72, 95–103, 106, 138, 139
  experiments, 81, 82, 96, 105
  rural development
    amid social and environmental changes, 102, 103, 105
    economic shocks, 96–100, 102
    plausible economic and environmental shocks, 72
    potential effects of severe floods, 95, 96
Returning farmland to lake policy, 20, 21, 40
Rice cultivation, 15
Rice yield functions, 79
Risk zones, 8
Robust analysis, 62, 93, 104, 112, 114, 124, 125, 135–137
Robustness analysis, 134–135
Rural development, 23, 71–74, 76–80, 83–88, 90–100, 102–106
  issues, 23
  PLR, future
    empirical data, 74–76, 83, 104
    entities, interactions, and feedbacks, 72–74
    limitation of model, 104, 105
    model design and implementation, 76–80
    model verification and validation, 80, 83, 134
    plausible economic and environmental shocks and resilience, 72
    resilience, 95–100, 102, 103, 106
    robustness analysis, 104
    subsidy policies, 71, 72, 83–88, 90–95
  resilience
    amid social and environmental changes, 102, 103, 105
    economic shocks, 96–100, 102
    potential effects of severe floods, 95, 96
  urbanization, 62–65
Rural households, 50, 113
  measuring well-being, 44–45
  surveys and interviews, 45
    income composition, 50
    income distribution, 50

Rural livelihoods, 50
flood impacts and equitable, sustainable development, 66
high-income households, 54, 56–58
households and constraints, 58–61
low-income households, 53, 54
micro- and macro-level processes, 43, 44
quantitative and qualitative analyses, 50–52
sensitivity to flooding and inequality in flood impacts, 61, 62
surveys and interviews, 45
income composition, 50
income distribution, 50
urbanization and rural development, 62–65
villages and local social, environmental factors, 52, 53
Rural-urban development dynamics, 63, 67, 111

S
Schelling's classic segregation model, 125
Sensitivity, 4–7, 10, 34
concepts, 5
definitions, 4
and exposure, 4
human development, 7
manifestations, 8
measures, 5, 8, 34
relative level, 35
rural livelihoods, 10
spatial variations, 8
Sensitivity analysis, 134
Single cropping, 15
Social capital, 59, 61
Social connections, 57
Social network analysis, 137, 138
Social vulnerability, 5
Subsidy policies
experiments for exploring, 83, 84
future, 71, 72
to large farms, 83, 84, 90, 91, 93–95, 105
to rental contracts, 91, 92, 105
to rice growers, 83, 90–96, 105, 106, 112
villages and adaptive policy, 92–95
villages with poor, average and good farmland resources, 85–88, 90–92
Sustainability, 2, 3, 138
Sustainability framework, 7–9
complex systems approach, 123
human-environment systems, 1–3
implementation
assessing well-being, 7, 8
complex processes underlying well-being, 8, 9
future paths of system, 9
for policy analysis, 3–5
potential usefulness, 5–7
Sustainable development, PLR, 116, 118–120
findings from study, 109, 110
framework for analyzing global sustainability, 116, 117
diversity of places, 116
global constraints, 116
global sustainability, 116
interconnections, human and environmental well-being, 116
interconnections, places, 118
local constraints, 116
local sustainability, 116
research questions and approaches, 118–120
trade-offs, 118
future development and policy recommendations, 111–113
implications, 113–115
vulnerability to sustainability, 115

T
Townships, PLR, 38–40
Trade-offs, 118
Tragedy of the Commons, 9
"Two-season" rice, 17

U
Unlimited Supply of Labor, 22
Urban clusters, 64
Urban development, 120
Urban *hukou*, 22, 23
Urbanization, 93
Urbanization and rural development, 62–65

V
Variables
government contacts, 45
relationships, 74
Village leaders, 57

W
Wu Bo Hu, 53