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**SPATIO-TEMPORAL DYNAMICS OF HOUSEHOLDS, FORESTS, AND THEIR IMPACTS ON GIANT PANDA HABITATS**

presented by

Li An

has been accepted towards fulfillment
of the requirements for the

Doctoral degree in Dept. of Fisheries and Wildlife

Major Professor's Signature

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# SPATIO-TEMPORAL DYNAMICS OF HOUSEHOLDS, FORESTS, AND THEIR IMPACTS ON GIANT PANDA HABITATS

By

Li An

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
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## ABSTRACT

### SPATIO-TEMPORAL DYNAMICS OF HOUSEHOLDS, FORESTS, AND THEIR IMPACTS ON GIANT PANDA HABITATS

By

Li An

Human-environment interactions have drawn increasing attention to researchers with different backgrounds and research purposes. Many researchers have pointed out the urgency of interdisciplinary integration due to the multifaceted and cross-scale (both spatial and temporal) nature in this type of studies. This dissertation research is an effort to address human-environment interactions using interdisciplinary data and models.

Using Wolong Nature Reserve (China) for pandas as the study site, the goal is to answer the question of how the household demographic features, human needs, attitudes, and activities, and government policies influence the spatio-temporal pattern of panda habitats. Fuelwood consumption is a major factor affecting panda habitat. Under this goal, I have the following objectives: 1) discern the factors that impact household annual amount of fuelwood consumption, 2) develop a household electricity (an available substitute for fuelwood) demand model, 3) understand how young adults leave parental homes and establish their own households, and 4) build a spatio-temporally explicit model that predicts habitat dynamics given results from objectives 1 through 3.

To address objectives 1 through 3, I interviewed 50 households in 1998, and 220 households in 1999. Through different modeling methods (i.e., STELLA

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systems modeling for objective 1, logistic regression modeling for objective 2, and structural equation modeling for objective 3), I found that (1) household age structure and cropland area are the most sensitive factors that determine (or impact) household fuelwood demand; (2) electricity price, voltage levels, outage levels are key factors that affect household electricity demand; and (3) parental attitudes/behavior, peer behavior, and perceived availability of material/non-material resources play a critical role in adolescents' home-leaving decisions.

With such data and findings, and additional data (e.g., 2000 population census data, household coordinates data) collected in 2000 and 2001, objective 4 represents an integrative effort that uses agent-based modeling approach, where all the individual persons, households, and land pixels are represented as relatively independent agents (concrete definition template, often observational unit), and their interactions are modeled, tested, and simulated in Java-Swarm platform under Linux 7.3 operating system. The findings suggest that human demographic factors (e.g., fertility, emigration, birth interval) and socioeconomic factors (e.g., providing cheaper electricity) could change panda habitat quantity and spatial arrangements greatly, especially in the long run.

Aside from reinforcing the need to include human demographic and socioeconomic factors in wildlife conservation efforts, this research has established a new interdisciplinary approach that includes as much individual-level information as possible. This methodology may be applicable to other human-environment studies in many other places.

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# ACKNOWLEDGEMENTS

This dissertation (maybe any dissertation) is not possible without tremendous assistance and support from a multitude of sources. Though words are inadequate to express my wholehearted appreciation, I still want to try and give acknowledgements to them.

This project is part of National Science Foundation (NSF) CAREER project "A Systems Approach to Assessing Impacts of Multiple Human Activities on Panda Habitat in Wolong Nature Reserve Landscape". Aside from NSF, National Institutes of Health (National Institute of Child Health and Human Development), American Association for the Advancement of Sciences, and The John D. and Catherine T. MacArthur Foundation also provided funds that allowed me to complete this dissertation.

My committee members, Dr. Angela Mertig, Dr. Jiaguo Qi, and Dr. Sandra Batie, provided valuable advice and guidance throughout the entire research process. It is my honor to have these wonderful people as my mentors, and I definitely owe gratitude to them.

The Department of Fisheries and Wildlife staff has always been a reliable source of help when needed or requested. Their efforts to keep the entire process moving smoothly are very important for the completion of this dissertation. These people include Jane Thompson, Julie Traver, Carla Dombroski, Jill Cruth, Susan Jones, and Sara Cline. Very special thanks should be given to James Brown, our UNIX doctor, for his important assistance in UNIX and Linux.

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I am indebted to Dr. William W. Taylor and Dr. Frank Lupi. Dr. Taylor provided valuable academic advice, and administrative help (I cannot remember how many recommendation letters he has signed for me!) during my stay in MSU. Let me say thank you, Dr. Taylor. Dr. Lupi spent a lot of time working on the paper that was published later, listening, discussing, and editing. Thank you, Dr. Lupi.

The interns who worked in the Liu-lab were a great help to my dissertation research. They include Joyce (Guijie) Wang, Yan Zhang, Yi Zhang, Gang Tang, and Hongxia Lu. Their excellent work and patience in data entry and preparation have definitely facilitated my research to proceed in a duly manner. I want to say thank you to these people.

The loyal friends and coworkers in Wolong Nature Reserve were of course a valuable help in my fieldwork. Without their time and efforts, this dissertation is impossible. These people are Jinyan Huang, Yinchun Tan, Lun Wang, Jian Yang, Shiqiang Zhou, and their wives. Due to these wonderful people, my fieldwork was not only effective, but also full of fun. I still remember the slopes we climbed together, the jokes we made with each other, and the so many sunrises and sunsets we enjoyed. I am also indebted to a few other people from the reserve: Hemin Zhang, Chunxiang Tang, and Hongying Han. I am also indebted to Dr. Zhiyun Ouyang from the Chinese Academy of Sciences for his thoughtful advice and important assistance.

My lab mates deserve recognition for their thoughtful advice, insightful comments on my papers (manuscripts) and oral presentations, and readily help

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when requested. They are (in alphabetical order) Scott Bearer, Xiaodong Chen, Guangming He, Edward Laurent, Christopher A. Lepczyk, Marc A. Linderman, Anita Morzillo, Daniel T. Rutledge, and Jialong Xie.

Finally, three people merit special mention, about whom I cannot say enough. Though words may not be a good vehicle for my gratitude and indebtedness, let me try.

First, it is my advisor, Jianguo Liu. His support, patience, and guidance throughout my study at MSU have been crucially important for this dissertation and for my career as well. His faith in me, his plenty of time and efforts in reading, revising, and editing my many proposals, manuscripts and papers, and his patience with me have been, and will still be, a valuable asset in my career. Thank you, Dr. Liu.

Second, my parents deserve special mention. They spent so much time and efforts in helping me overcome countless barriers during my childhood and adulthood. Their love and care are one of the assets that I most cherish and rely on. I cannot thank them enough.

And lastly, it is my wife Yanqun Zhou, the wonderful woman I have in my life. Thanks to her love, care, suggestions, advice, and tears (sometimes!!), I survived many difficulties. While she was still my girlfriend and fiancée, she spent so much time and effort helping me, academically and logistically. My recent fancy web-page is an evidence of her devotion to me.

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# INTRODUCTION

Though the last decade has seen a wide acceptance of making transition towards sustainable development (United States National Research Council 1999) environmental sustainability of the earth's life support systems has been greatly degraded due to an exceedingly rapid loss of biodiversity (Wilson 1988). Paralleling the growth in scientific research into the role of biodiversity in maintaining environmental sustainability (such as providing vital ecosystems services) and the increasing recognition of biodiversity's esthetic value, a new research agenda (i.e., sustainability science) has been proposed to study how multiple environmental stresses, social institutions and ecological conditions interact in particular places and affect biodiversity status (Clark 2002). Within this agenda, special attention should be paid to the following issues: (1) bridging the artificial but harmful divide between basic and applied research and manage boundaries between disciplines or across geographical scales (Cash and Clark 2002, Clark 2002), and (2) developing an integrative framework with global and local perspectives included so as to build a "place-based" understanding of the interactions between society and the environment (United States National Research Council 1999).

Many other researchers have also pointed out the urgency of interdisciplinary integration due to the multifaceted and cross-scale (both spatial and temporal) nature in sustainability science, where mechanisms underlying many socioeconomic or biodiversity-related changes are of particular interest (e.g., Clark

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(e.g., Clark 2002, Clark et al 2000, Daily 2001, Liu 2001, Liu et al 2001). It is further suggested that integrated assessment models, scenario building, and regional information systems be developed and applied to facilitate this integration, "explore what the future may hold", and "test the likelihood of achieving the (sustainability) goals…under varied assumptions about human development and the environment" (United States National Research Council 1999). However, complexities of many social or individual choices in such coupled society-biodiversity systems (with variant socioeconomic/demographic/ biodiversity factors intertwined) have often been hurdles to build such models and scenarios (Gimblett 2002).

Theories and methods of complex systems have been proposed to deal with these complexities, because the individualistic demographic and socioeconomic properties of our study targets can be captured and represented in modeling the choices and decisions of each resource consumer. Bottom-up approaches such as agent-based modeling (usually in relation to artificial intelligence) often play a crucially important role in this type of modeling processes. Agent-based modeling is a methodology that predicts or explains emergent higher-level phenomena by tracking the actions of multiple low-level "agents" that constitute or at least impact the system behavior at broader scales.

An excellent site to address the above complexities is Wolong Nature Reserve (China), for the following reasons. First, established in 1975 (with an area of 2,000 $km^2$) for conserving the giant panda (*Ailuropoda melanoleuca*), the reserve is v

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reserve is within one of the 25 global biodiversity hotspots (Myers et al 2000), where over 2,200 animal/insect and over 4,000 plant species (Wolong Administration 1987) cohabit with the giant panda in a diverse biophysical environment (e.g., the elevations range from 1,200 to 6,250 m). Among varying levels (e.g., genetic, population, species, and ecosystem) in biodiversity studies, the habitat approach has proven to be significantly based on the utter dependence of organisms on an appropriate environment (Ehrlich and Wilson 1991) especially considering the famous species-area relationship in island biogeography (i.e., $S=cA^z$, where S is the number of species that occur in a region with area A, and c and z are suitable constants, see MacArthur and Wilson 1967) their habitats implies conserving local biodiversity. Second, though standing as a "flagship" reserve in China with substantial financial and technical support from domestic and international organizations, Wolong has a human settlement following a traditional rural lifestyle, in which fuelwood is used for cooking throughout the year and for heating in winter. The available substitute for fuelwood, electricity, is subject to problems such as relatively high price and low reliability, and cannot be used as the major energy source. This situation has made its biodiversity highly subject to human activities and policy changes. Third, the giant panda uses forest as cover, and understory bamboo as food sources (Schaller et al 1985) been degraded in quantity and quality due to a rapid increase in rural population and the number of households.

My dissertation, entitled "Spatio-temporal Dynamics of Households, Forests, and their Impacts on Giant Panda Habitats", is an effort to build an

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integrated assessment model and to answer the question of how the household demographic features, human needs, attitudes, and activities, and government policies impact the spatio-temporal pattern of panda habitats. Through my intensive fieldwork from 1998–2002 with colleagues from MSU and Wolong, I have assembled a wealth of empirical data on both social and environmental factors and built a Wolong Regional Information System (WRIS) in both Microsoft Access and Geographic Information Systems (GIS). For instance, seven high-quality remotely sensed satellite images ranging from 1965 to 2000, a digital elevation model, and the coordinates of all the households obtained by global positioning system (GPS) measurement and GIS extrapolation are available. Also readily usable are the 2000 Population Census data of Wolong (the census was nationwide and implemented by all levels of governments), and face-to-face interview data of 220 households (about 1000 households in total) regarding household economic status, social network (kinship relationship), and attitudes towards such issues as fertility. Answering the following questions is necessary to achieve my goal:

(1) Household Fuelwood Demand: what factors, in what ways, impact the annual amount of fuelwood consumption given a household with certain socioeconomic features?
(2) Household Electricity Demand: What factors, in what ways, impact the annual demand for electricity, an available substitute for fuelwood?

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(3) Household Dynamics: how many new households would be established over the entire landscape of Wolong given certain attitudinal/contextual factors (e.g., immigration/emigration policy)?

(4) Spatial Deforestation Dynamics: what locations, to what extent, would be deforested to satisfy local residents' fuelwood needs, given results from (1) to (3)?

Answering question (1) has led to a publication in Ecological modeling (An et al. 2001), co-authored with Jianguo Liu, Zhiyun Ouyang, Marc A. Linderman, Shiqiang Zhou, and Heming Zhang. Chapter 1 delves into the construction, verification, and validation of this household-level fuelwood model, where the writing style is primarily in accordance with that of journal Ecological Modeling.

Chapter 2 focuses on an econometric model predicting electricity (an available substitute for fuelwood) demand based on a number of demographic and socioeconomic factors, which answers question (2). Since this chapter has been published in Ecological Economics (An et al. 2002), its style conforms to this journal. Frank Lupi, Jianguo Liu, Marc A. Linderman, and Jinyan Huang are coauthors for this paper.

Chapter 3 deals with a structural equation model that predicts and/or explains the behavior of leaving parental home and household formation using a set of psychosocial factors such as peers attitudes toward leaving parental homes, the perceived resource availability, and the individualism tendency, which is an effort to answer question (3). This chapter has been published in Population and the En

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and the Environment: A Journal of Interdisciplinary Studies with Angela Mertig and Jianguo Liu as coauthors (An et al. 2003a).

Chapter 4 is an effort of integrating above data and models into an Integrative Model for Simulating Household and Ecosystem Dynamics (IMSHED), which is the key component of this dissertation. This chapter relies heavily on agent-based modeling (ABM), a bottom-up tool appropriate for running "simulations allowing deductions to be made about the causal linkages between organizational hierarchies, spatial scales, and dynamics" (Schmitz 2001). The life history of each person is tracked, where all events that would possibly occur in a local person's life are simulated using computer modeling. Paralleling the life history of individual persons (members of households), individual households undergo corresponding changes—their sizes may increase or decrease, new households may be established, and some old households may be dissolved. Given the household dynamics and demand for fuelwood, the IMSHED model links households (including their dynamics and all the socioeconomic factors) and their demands for fuelwood with presently available forests in the landscape. With "knowledge" about themselves (e.g., attitudes toward electricity purchase affordability), other agents (e.g., kinship relation, crop planting habit), and the environment (the shortest distance to the available forest), the household agents interact with each other (e.g., through information exchange) and the environment (represented as gridded cells) through their activities (e.g., fuelwood collection). The households and environment co-evolve over time and space, resulting in macroscopic forest and habitat dynamics. This chapter was presented i

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presented in the Population Association of America 2003 Annual meeting and will be submitted to Ecological Modeling for publication (An et al 2003b), coauthored with Marc Linderman, Ashton Shortridge, Jiaguo Qi, and Jianguo Liu.

The last chapter (Chapter 5) is an application of the IMSHED model developed in chapter 4, trying to study how changes in socioeconomic and demographic factors could change panda habitat over space and time. This chapter also was presented in the Population Association of America 2003 Annual meeting, and will likely be submitted to Biological Conservation or The Society and Natural Resources for publication. Guangming He, Zai Liang, and Jianguo Liu have coauthored this paper.

Each of these five chapters, though slightly different in writing style (depending on the journal it has been published or will be submitted to), revolves around one theme: protect panda habitats with as many human-environmental interactions studied and integrated as possible. Different methods and models, including household interviews, Geographic information Systems (GIS), and agent-based modeling (ABM), have contributed to this interdisciplinary study.

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# CHAPTER 1

# SIMULATING FUELWOOD DEMAND IN RELATION TO DEMOGRAPHIC AND SOCIOECONOMIC PROCESSES ON HOUSEHOLD LEVEL

Special gratitude to

Jianguo Liu, Zhiyun Ouyang, Marc A. Linderman,
Shiqiang Zhou, and Heming Zhang

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## Abstract

Human activities have significantly affected wildlife habitats. Although ecological effects of human impacts have been demonstrated in many studies, the socioeconomic drivers underlying these human impacts have been seldom studied. We developed a household-based, stochastic, and dynamic model that simulates the impacts of household demographic and socioeconomic interactions on fuelwood use, a key factor affecting the quantity and quality of habitats for the giant pandas (*Ailuropoda melanoleuca*). Using Wolong Nature Reserve (China) as a case study, this model mimics household production and consumption processes and integrates various demographic and socioeconomic factors. Household interviews conducted in 1998 within the Reserve provided the data for parameterization. The simulation results fit well with both the data used in constructing the model and with a set of independent data. Household age structure and cropland area were found to be the most sensitive factors in terms of fuelwood consumption, and thus deserve more attention in panda habitat conservation. This model could help reserve administrators to understand the interrelationships among local economy, local cultural traditions, and habitat degradation, facilitating more scientific and economically efficient policymaking.

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## Introduction

Human activities have caused serious disturbances to wildlife populations and their habitats (e.g., Wilson 1988, Ehrlich 1995). Previous research has mostly focused on the ecological effects of human activities, such as the effects of agricultural land development on wildlife population abundance (Freemark and Csizy 1993, Sietman et al. 1994, Warner 1994), as well as the influences of timber logging on biomass (Hollifield and Dimmick 1995, Norwood et al. 1995), animal home range change (Ims et al. 1993, Linnell and Andersen 1995, Chang et al. 1995), and species distribution and composition (Lyon 1979, Geier-Hayes 1989, Skovlin et al. 1989, Nelson et al. 1996).

In addition to the understanding of these ecological effects, conservation biologists have also observed that human population size, economic activities, and attitudes (e.g., attitudes towards childbirth) interact with each other and ultimately result in ecological effects (Liu et al. 1999a). These interactions and the underlying mechanisms, though only intuitively understood (Dompka 1996, Liu 1997), have been demonstrated to be critically important in terms of conservation applications (e.g., effective wildlife management, Liu et al. 1999a, b). Additionally, exploration towards these issues has triggered integration of ecology, economics, and modeling techniques (e.g. establishment of spatially explicit models, Liu 1993 and Liu et al. 1995).

Quantitative computer modeling has been an effective method for integrating ecological and socioeconomic factors (Costanza et al. 1991, Liu 1993). It helps to understand the dynamics of the processes of interest by mimicking

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"mimicking the actual but simplified forces that are assumed to result in a system's behavior" (Hannon and Ruth 1994). For instance, quantitative computer modeling has been successfully used in studying wildlife population dynamics (Liu 1993, Conroy et al. 1995), comparing alternative management strategies (Liu et al. 1994, 1995, Turner et al. 1995), and interpreting the spatial connectivity of processes within a specific habitat (Hanson et al. 1988). All these studies were largely conducted on region or landscape scales, seldom on the household level, which is actually the basic unit of human production and consumption in rural areas and thus deserves more attention for wildlife conservation. In addition to this scale issue, literature on using modeling to integrate both attitudes and economic incentives into household level decision processes for wildlife conservation, to our knowledge, is not available.

We developed a household-based and stochastic dynamic model, named "Panda habitat_Demographic, Ecological & Economic Model" ("PANDA_DEEM" thereafter), to simulate household level consumption and production processes, demographic and socioeconomic dynamics, and their interactive effects on habitats for the giant pandas (*Ailuropoda melanoleuca*). By integrating economic, demographic and ecological data into a systems model, PANDA_DEEM is designed to disclose the underlying mechanisms for habitat fragmentation and loss. Because forests are an important component of panda habitats (Hu et al. 1980, Schaller et al. 1985), PANDA_DEEM takes *fuelwood use quantity* as an indicator of the giant panda habitat disturbances caused by human activities. The more fuelwood is used, the more trees need to be cut and forests destroyed.

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Previous research shows that fuelwood consumption has contributed most to the loss of panda habitats (Liu et al. 1999a).

In this paper, we begin with an introduction to the study area and the model structure. We then focus on methods for model parameterization and model testing (including model verification, model validation, sensitivity analysis, and uncertainty analysis). Finally, we present results of model testing and discuss the implications of the model.

## Methods

### Study area

Wolong Nature Reserve (102°52'-103°24'E, 30°45'-31°25'N, Figure 1.1) is located in Sichuan (one of the most populated provinces in China) with an area of approximately 2,000 $Km^2$. Four major ethnic groups, i.e., Han, Tibetan, Chang, and Hui, constitute the total rural population of 4320 people in 1998, corresponding to a total number of 942 households. These households mainly rely on growing corn, potato, and vegetables for subsistence and use fuelwood as their main energy source for cooking and heating in winter. Pig feeding, collection of Chinese medicine herbs, timber harvesting, transportation, construction of local roads and hydropower stations, as well as house building are also their main activities besides farming. The famous "one child policy", which is strictly implemented in urban areas, does not apply to this area populated by minority groups (Tibetan, Chang and Hui) due to loose governmen

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governmental control in rural areas with minority groups. The average number of children per couple in Wolong is 2.5 (Liu et al. 1999b).

As the largest of China's 25 giant panda reserves, Wolong Nature Reserve was designated in 1963 with an area of 200 $Km^2$ and expanded to approximately 2000 $Km^2$ in 1975. The 34 years since 1975 have witnessed a drastic giant panda population decline—from 145 animals in 1974 (Schaller 1985) to 72 animals in 1986 (China' Ministry of Forestry and World Wildlife Fund 1989), paralleled with a fast human population increase (an increase of approximately 70% from 1975 to present). As a national treasure of China as well as a precious natural heritage of concern to people around the world, this most endangered species, the giant panda, has been attracting increasing national and international attention. For instance, World Wildlife Fund (WWF) has adopted the giant panda as its logo.

**Conceptual model and data sources**

PANDA_DEEM consists of three submodels and their interrelationships are demonstrated in Figure 1.2. (1) Submodel *DEMOGRAPHY* includes the number of people per household, age structure, and educational level. Local residents' attitudes towards birth and education are key factors influencing the demographic features of the household—specifically, the number of children, and the educational level. (2) Submodel *ECONOMY* consists of two main components. One is *Production_and_Consumption* of the simulated household, and the other is *Incomes_and_Expenses*. *DEMOGRAPHY* determines the extent of *Consur*

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of *Consumption* and provides the necessary labor for *Production.* Component *Incomes_and_Expenses* simulates all the income and expense items that could occur in a household with the above demographic, consumptive, and productive characteristics. *Incomes* is mostly determined by *DEMOGRAPHY*, e.g., availability of labor (people between 21 and 60 in the model) and educational level of labor (average schooling years of labor). *Incomes* is also associated with *ECONOMY* (*Production* specifically). *Expenses* is mainly determined by *DEMOGRAPHY*, such as number of people and age structure of the household. *Production* and *Consumption* can impact *Expenses*, e.g., growing crops needs chemical fertilizers. (3) Submodel *FUELWOOD* is driven by the following factors: *DEMOGRAPHY*, *Production* (fuelwood used for cooking pig fodder), and *Consumption* (fuelwood used for heating in winter and for household food cooking).

The data for parameterizing PANDA_DEEM were obtained from the interviews with 50 households, conducted by the authors from June to August 1998 in Wolong Nature Reserve. The 50 households were randomly selected in Wolong Township (one of the two townships in the Reserve), the region where most of the pandas inhabit. The questionnaire includes (1) fuelwood use; (2) incomes and expenses; (3) production and consumption; and (4) demography. We also asked the interviewees about their attitudes towards some social issues, such as the number of children they prefer to have, marriage age they prefer, and the schooling years they prefer for their children.

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All the interview results were entered into a Microsoft Access database. The information from five of the households was unreliable because their estimates of fuelwood consumption were inconsistent with their consumption and production needs. Thus the associated data from these five households were excluded from use. From the remaining 45 households, we randomly selected 30 households for model development and the other 15 households for model validation.

## Submodels

### Submodel *DEMOGRAPHY*

This submodel is individual-based, simulating life history of an individual as he/she goes from birth (or the starting point of the simulation if the individual is already in the household, or the year when the individual moves into the household), through each age group, to death (or the end point of the simulation if the individual is still alive, or the time when the individual moves out) in an annual time step. The age-group classification is based on the status of occupation which an individual at a certain age is most likely to take: (1) age 0-5—infant to preschool period; (2) age 6-12—elementary school period; (3) age 13-15—middle school period; (4) age 16-20—high school or technical school period; (5) age 21-60—adult period when people work as main labor force; and (6) age 61 and over—retirement period. The individual stays in that age group until the age exceeds the age group's upper threshold when the individual moves into next age group (Figure 1.3).

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The model incorporates the following events, possibly taking place in a person's life, into the model: birth, death, emigration out of the household through marriage or going to college, and immigration into the household through marriage (the main legal way for moving into the Reserve). As to the death process, the model creates a random number (between 0 and 1) for each individual each year and compares it with the mortality associated with the corresponding age group (Figure 1.4). If the random number is smaller than the mortality of the group to which the individual belongs, then the individual dies; otherwise survives and moves into the next year. This process repeats every year until the individual dies, moves out of the household, or the simulation ends. The yearly mortality rates of different age groups of the whole Reserve (1994-1996) were used as equivalents to death probabilities for an individual over time: 0.745% for age 0-5 group, 0.090% for age 6-12 group, 0.131% for age 13-15 group, 0.196 % for age 16-20 group, 0.291% for age 21-60 group, and 5.354% for age 61+ group (Wolong Nature Reserve, 1994-1996).

There are two major types of emigration: emigration through marriage and emigration through education. Emigration through marriage is based on the fact that girls generally tend to move out of the household and live with their husbands, and that boys set up new households after marriages. This event is set to occur at the age of 22, the average marriage age calculated from our field data. For simplicity, all the children except the youngest move out of the household when they reach 22 years old (Figure 1.5). Emigration through education is based on the fact that if a young person could go to college or technical s

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technical school he would find a job in city instead of staying in the household as a farmer (Liu et al. 1999a, b). Our data show that 9.6% of the people in the age group 16-20 passed the national entrance examination and went to colleges or technical schools in 1996, thus the probability that an individual in this age group will go to college and move out is set at 0.096 (Figure 1.6).

Immigration into a household is based on the fact that one child (usually the youngest son or the youngest daughter in case of no son in the household) stays with his/her parents, bringing his/her spouse into the household at the time of marriage (22 years old on average). The probability that the youngest children stay with their parents is 0.941. So his/her spouse immigrates into the household with the same probability of 0.941. The corresponding flows are shown in Figure 1.5.

**Submodel *ECONOMY***

This submodel consists of two components, *Production_and_Consumption*, and *Incomes_and_Expenses*. The type and magnitude of *Production_and_Consumption* are closely related to the typical life style of a rural household in Wolong. The amounts of corn, potato, rice, and pork are set to be state variables because they constitute the dominant food that local households rely on. Farmers grow potatoes and corn as their staple crops, exchanging most of the potatoes for rice, and using most of the corn to feed pigs. A special type of radish is planted in winter as complementary fodder for pigs (Figure 1.7). The pork (or bacon) thus produced was mainly for household use, but an increasing portion of

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portion of it has been used for trade as the number of tourists, the main purchasers of local bacon, increases over time. Self-consumed vegetables, including beans, celery, and radishes, are ignored in the model because they are of relatively small quantities. Furthermore these vegetables use a small portion of land (often intercropped with the staple crops or planted in winter, non-growing season of the staple crops) and time. The only commercial vegetable, cabbage, is taken into account in the model because it is one of the important income sources.

The input to this *Production_and_Consumption* cycle includes land and labor. The amount of land is controlled by the government, whereas the availability of labor is associated with the present household demography, which in turn is determined by the government birth control policy and the farmers' birth attitudes. This *Production_and_Consumption* cycle impacts the amount of fuelwood use through two ways: (1) corn and radishes have to be cooked before being fed to the pigs; and (2) most of the food items (e.g., potatoes, vegetables, pork, and rice) have to be cooked for human consumption.

The following paragraphs discuss the important parameters for this submodel. (1) When corn is used to feed pigs, the input-output ratio is approximately 6:1, implying that the consumption of 6 units of corn by pigs can bring about 1 unit of pork. The input-output ratio for potato and pork is 12:1. (2) The average productivity of radish is 30,000 kg/ha; the average area for planting (used as model input) radish is 0.146 ha; and the input-output ratio for potato and pork is 13:1. (3) The rate of exchanging potatoes for rice is 3.5, i.e., 3.5 units of potatoes

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potatoes are equivalent to 1 unit of rice in the market. (4) The regression between household size and household potato use quantity per year is:

*Household_Potato_Use = 79.638 * Household_Size-30.656* ............(1)

*(n=28, $R^2$=0.476, p=0.000048)*

The total production of potato (or corn) is determined by its productivity, once the total area of land is fixed. Corn productivity and potato productivity were positively associated with per hectare expense. Because observed values of corn and potato productivity are never below 600 Kg/Ha and 11250 Kg/Ha, respectively, we used a maximal function to select a higher value between the calculated and the lower limit values:

*Corn_productivity = Max (1937.100 * LOGN (Per_hectare_expense) – 11254.000, 600.000)*.................................................................................. (2)

*(n=30, $R^2$ =0.56, p<0.0001)*

*Potato_ productivity = Max (5662.900* LOGN (Per_ hectare_ expense) – 29342.000, 1250.000)* ..........................................................................(3)

*(n=30, $R^2$ = 0.591, p<0.0001)*

However, if there is no labor (number of people between 21 and 60 is zero), we assume that the productivity would be reduced by multiplying a Corn_labor_index of 0.8. In the Reserve, we did observe that the households without labor had a lower productivity even though they hired relatives and friends to help them with the farming work. This situation is also the case for potato productivity.

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Rice is the staple food in Wolong, but not grown there. In order to obtain enough rice, local residents usually use potatoes to exchange for rice from the outside market. If the rice from the exchange is not enough to meet the household demand (household size* per capita need, 148.5 Kg/person—an average of the selected 30 households in 1997), we assume that extra money will be spent to purchase the rice needed.

Pork is the basic meat in Wolong. Our interview showed that almost every household had enough pork to eat, so the total quantity of pork demand of each household was equal to household size times per capita use. However, pork is not purchased from local markets in case of shortage because local residents can reduce pork consumption by increasing the consumption of other food, e.g., rice, potatoes, and sometimes meat of wild pigs obtained from poaching. Any surplus pork is sold. The market price for pork was 12 Yuan/Kg in 1997 and 1998 (1 US$ = 8.3 Yuan).

Another very important component in the submodel *ECONOMY* is *Incomes_and_Expenses*. The difference between incomes and the expenses, i.e., yearly net income, is set to be a state variable because it represents the economic status of the household, and determines (at least affects) household expense decisions. The potential income sources for a typical household include cabbage sale, herb sale, pork sale, constructing roads, local transportation, and temporary jobs. The potential expenses include children's schooling, purchase of electricity, purchase of rice, farming facilities, and subsidiary substance

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("Substance" in Figure 1.8) that refers to alcohol, cigarettes, salt, soybean sauce, and so on (Figure 1.8).

All the incomes or expenses in the future should have been converted to present values by using a discount rate if we were interested in the accumulated incomes or expenses. However, the amount of fuelwood consumption at a given time, which is our focus in this model, is the function of various demographic, income, and expense factors at that time. As long as the function (the relationship between the annual amount of fuelwood consumption and those demographic, income and expense factors) does not change over time, there is no need to discount the future money and calculate its present value. Furthermore, for short-term simulations presented in this paper, no significant differences exist between using and not using a typical discount rate (5%).

Transportation includes the shipping of local agricultural/forest products to the outside and industrial/consumptive goods to the reserve. Transportation of goods can provide the highest income (13250 Yuan on average) if a household is able to do it, but few households can afford it because of the high expense to purchase vehicles. This income requires three prerequisite conditions: at least 3 years of education (the smallest number of schooling years for those households owning trucks observed in the survey), at least 20,000 Yuan of accumulated savings (half of the price for a small truck—we assume this is necessary for buying a truck based on our communications with farmers), and enough labor (the number of people between 21 and 60 is greater than or equal to 1).

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Income from temporary jobs refers to the income from such jobs as building hydropower stations, building houses for other residents, and working in local restaurants. It depends on the availability of the labor and the average schooling years of the labor. If the household head is illiterate (all the households with income from temporary jobs have schooling years larger than 0), or the number of people between 21 and 60 (defined as labor in this model) is zero, the household is not able to obtain this type of income. Otherwise the household gets an average annual income of 1421.790 Yuan.

Road construction requires physical power and results in a relatively low income of 750 Yuan per year (25 Yuan/day, 30 days/year on average). Thus we assume no income arises from road construction for a household that has no labor or gets transportation income. Otherwise if the random variable creates a value less than 0.350 (35% of the local farmers obtained road construction income in 1997), the household can earn an average of 750 Yuan.

Like road construction, herb collection requires physical power and the associated income is relatively low. Thus, if the household receives income from transportation or no labor exists, herb income is set at zero. In addition, because no households with 9 or more schooling years collect herbs, we set this variable to zero if the educational level is equal to or greater than 9 years. Otherwise if the random variable creates a value less than 0.47 (14 out of 30 households have herb income), the herb income is set to be the function of the educational level (in terms of schooling years of the labor in the household):

$$Herb\_income = -123.100*Education\_level + 1093.000 \quad (4)$$

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*($n=14$, $R^2=0.528$, $p<0.0001$)*

Cabbage sale is one of the main income sources in Wolong Nature Reserve. Approximately 96% of the farmers plant cabbage. We found cabbage income (Yuan) has a significant positive relationship with the cabbage land area (ha):

$$Cabbage\_income = 20515.000 * Cabbage\_land - 161.380 \qquad (5)$$

*($n=25$, $R^2=0.609$, $p=0.0000042$)*

Local residents tend to satisfy their demands for pork/bacon first and sell the extra in the form of bacon. The conversion rate from pork to bacon is approximately 0.6-0.7, because pork loses weight due to water loss when it is processed by smoke. Consequently, bacon has a higher price than pork. The total amount of income, whether from pork sale or bacon sale, is almost the same. So bacon income is only set to be a function of the amount of pork available. Specifically, bacon income occurs only if the household has extra pork, which is the difference between the quantity of pork available in a given year and the quantity needed by the household. The quantity of pork available in a given year depends on the amount of corn, radish and potatoes used to feed pigs; the quantity needed by the household is the product of household size times the per capita yearly consumption.

Household expenses include children's schooling costs, electricity costs, purchase of rice, farming facilities, and subsidiary substance. In order to obtaining the annual average expenses that a household has to spend for one student ir

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student in elementary school, middle school, and high school, we did a pre-interview of ten households. The associated results were 335 Yuan/year, 1842 Yuan/year, and 5175 Yuan/year for elementary school, middle school, and high school expenses, respectively (the corresponding results based on those 30 households that were later used for model verification are 355 Yuan/year, 1750 Yuan/person, and 3940 Yuan/person).

Elementary schooling expense occurs when there are children between 6 and 12 years old in the household. The Chinese government requires all children go to elementary school, so the probability that a household sends their children to elementary school ($R_1$) was set at 1. One child in elementary school needs an average of 355 Yuan per year for enrollment and textbooks. The total expense for elementary school $S_1$ is as follows:

$$S_1 = 355 * Number\_of\_children\_aged\_6\_and\_12 \quad (6)$$

The data from the pre-interview showed that the average expenses for a middle school student and a high school student were 1842 and 5175 Yuan, respectively, and that not all parents were able to or wanted to, send their children to middle or high school, as they spent their limited income first on basic needs such as food, electricity, and farming facilities. Thus we used yearly net income as a criterion to determine whether a household will send children to middle school and high school. Because yearly expense for middle school is 1842 Yuan, we set three levels of net income, 1842, 921, and 500 Yuan, to test what farmers would do if their net income is enough to pay the total (1842 Yuan), a half (921 Yuan), or only a small portion of the schooling expense (500). We then surv

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then surveyed their willingness to send their children to middle school and high school at different levels of net income. If household net income per year is between 500 and 921, between 921 and 1842, or greater than 1842, 29.1%, 51.0%, or 68.2% of the respondents, respectively, said they would send their children to middle school. In case the household yearly net income is below 500 Yuan, we assume the probability is zero. One point that should be made is that since the income levels of 921 and 1842 were based on results of the pre-interview of the 10 households rather than the results of the 30 households used for model verification, the probabilities thus obtained should not exactly represent the probabilities for those 30 households. We will show later in the section "Results" of chapter 1 that the model outcome is not sensitive to income and expense variables such as middle school and high school expenses. Therefore, we still used the income levels from the pre-interview and the associated probabilities in the model.

Similarly, when household net income is between 1000 and 2588, between 2588 and 5175, or greater than 5175, 15.4%, 29.3%, or 56.0% of the respondents, respectively, said they would send their children to high school.

If the number of people between 13 and 15 years old is greater than 1 and the random variable creates a number less than $R_2$ (the probability that the household would send their children to middle school), the yearly expenses for middle school are $S_2$:

$$S_2 = Number\_of\_people\_between\_13\_and\_15 * 1842 \quad \text{......................(7)}$$

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where $R_2$ =0.291, 0.510, or 0.682. The assignment of values to $R_2$ depends on the corresponding net income in the previous year. If a household had a very low net income (less than 500) but still wanted to send their children to school, a binary variable ("MidSchl Intention" in the model, 0 for no and 1 for yes) would be used. We set the default value of this variable to be 0 because a household generally does not send their children to school if they have very low net income—their subsistence needs (e.g., food and clothes) should be met first. However, when we want to test what would occur for a low-income household that wants to send their children to middle school, we set it to be 1. In this case as well as other cases, where yearly net income is lower than the average expense for middle school (1842), debt will occur (net income is negative).

Similarly, the yearly expenses for high school ($S_3$) are calculated by using equation (8) if the random variable creates a value smaller than $R_3$ (the probability that the household would send their children to high school):

$$S_3 = Number\_of\_people\_between\_16\_and\_20 * 5175 \quad (8)$$

where $R_3$ = 0. 154, 0.293, or 0.560, depending on the corresponding net income.

Every household uses electricity for lighting and for appliances such as TV, but the extents to which farmers use electricity differ with per capita income. In light of the fact that no household spent more than 720 Yuan for electricity in 1997, we used a minimal function to restrict the electricity costs:

$$Yearly\_electricity\_expense = Min\ (0.109*Per\_capita\_income + 37.870, 720.000) \quad (9)$$

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Rice expense occurs if the amount of rice exchanged from potatoes is smaller than the amount needed, which is expressed as follows:

*Rice_expense = (Rice_needed – Rice_obtained)*Rice_price*...............(10)

*Rice_needed = Household_size * Per_capita_rice_need*....................(11)

*Rice_obtained = Potato_for_rice/Market_exchange_rate*....................(12)

where *Per_capita_rice_need* and *Market_exchange_rate* are set at 150 Kg/person and 3.5, respectively.

Farming expense, including expenditure on seedlings, chemical fertilizers, land films (used to keep corn seedlings from freezing damage), and tools, is equal to per hectare expense (Yuan/ha) times land area (ha). Average expense per hectare is 2026.8 Yuan.

Expenses for subsidiary substance ("Substance" in Figure 1.8), including alcohol/beer, cigarettes, salt, and soybean sauce, are a positive function of household size:

*Substance_expense = 83.029 * Household_size –55.673*................(13)

*(n=30, $R^2$ =0.466, p<0.0001)*

Expenses for others refer to money used for clothes, religious activities, medical services, and some other social activities (e.g., sending gifts to a household with a newborn baby, giving money for a relative's wedding). It is a function of yearly income:

*Other_expense = 630.270 * LOGN (Yearly_income) –3651.400*.........(14)

*(n=30, $R^2$ =0.562, p<0.0001)*

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For those households with trucks, we assumed that they get loans from friends, credit unions, or banks and would pay back later. If the purchasing expense is X yuan and the household decides to return Y Yuan each year, then this loan return has to last for X/Y years. Here X and Y were set to be 40000 (the price of a new small truck, Jian Yang 1999, personal communication) and 5000 Yuan, respectively.

Yearly net income is connected to another state variable called "Accumulated_Savings". Yearly net income goes into Accumulated_Savings at the end of each year if it is positive. If it is negative, the money in Accumulated_Savings is used to offset the deficit (Figure 1.8). If yearly net income keeps negative over time, there is a great possibility that some local residents resort to illegal activities such as clandestine logging and poaching (Jian Yang 1999, personal communication) thus the dynamics of yearly net income deserves extensive attention in terms of wildlife conservation.

**Submodel *FUELWOOD***

Household fuelwood consumption, a factor directly affecting panda habitat, is driven by demands from heating, cooking, and pig fodder cooking. Fuelwood consumption quantity for heating in a households without a senior person (61 years old or above) was set at a constant (7.23 $m^3$ /year, an average of fuelwood consumed for heating) because there was no statistically significant relationship between the quantity of fuelwood for heating and household size. Whether or not there is a senior person in the house, however, does affect the amount of fuelwooc

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fuelwood used for heating. A household with a senior person starts heating from early October to mid-April, lasting approximately 190 days; while that without a senior person does this from late October to early April, lasting approximately 160 days. Assuming the quantity of fuelwood use per day is a constant, a household with a senior person should consume 19% ((190-160)/160) more fuelwood than that without a senior person, i.e., 7.23 * (1+19%) = 8.60 $m^3$ /year.

The annual amount of fuelwood used for cooking is a function of the household size:

*Fuelwood_for_cooking = 0.467* Household_size +0.703*..................(15)

*(N=30, $R^2$= 0.533, p=0.0000046)*

Fuelwood for pig fodder cooking depends on how much pork is converted from potatoes, corn and radishes. We calculated the average ratio between fuelwood for cooking pig fodder and pork produced, which is 0.0106 (SE = 0.0038) $m^3$ /Kg, indicating that 1 Kg of pork produced consumes 0.0106 $m^3$ of fuelwood.

**Model programming**

PANDA_DEEM was programmed using STELLA 5.0 (High Performance Systems, Inc. 1997). A friendly graphic interface was developed to facilitate the communication between the user and the model.

The initial values of the state variables described in Section "Submodels" were set at the average values of the associated variables. One exception is that the initia

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the initial net income was set at 0 because we wanted to exclude the historical effects of net income.

**Model testing and simulation**

Model testing aims at justifying the reliability of the model and providing confidence for model application. Four approaches (model verification, model validation, sensitivity analysis, and uncertainty analysis) were used to achieve this goal. As mentioned in Section 'Submodels", we already obtained the equations and the parameter values for submodels *FUELWOOD* and *ECONOMY*. Submodel *DEMOGRAPHY* needs household size and ages of all the household members as model inputs. For simplicity, a concept of "typical household" is used for model testing and simulation. A typical household is defined as a household with 5 people (three generations), one grandparent, two parents, and two children. The reason why we set household size to be 5, and chose two children and one senior person, is based on the following estimation: the average household size of the 30 households is 5.2 people, and 40%, 33%, and 3% of these 30 households have 2, 3 and 1 children/child, respectively. Thus we chose 2 children, 2 parents, and 1 grandparent for this typical household.

We ran the model for different replicates and then calculated the average of fuelwood consumption amounts. These tests indicated that 50 runs could produce a relatively stable outcome. Because we were most interested in structural interactions between different variables in the submodels, we decided to use a short time length to run the model so that the basic structure of househo

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household demography does not change. A number of runs showed 4-6 years could keep the age structure of the typical household unchanged but still allow for some stochastic processes (e.g., whether a child of 9 years old at the beginning of simulation can go to middle school or not by the end of simulation) to function. We used five years as the time length. The model can be easily extended to do long-term (10 years or over) simulations.

**Model verification**

We first used the data from the 30 households for model development to verify the model results. This approach can be divided into the following steps. (1) Set the values of the demographic and socioeconomic variables to be exactly the same as those in the corresponding household. (2) Run the model 50 times (replicates). (3) Calculate the average of each run over time (5 years). (4) Calculate the average of all the above 50 replicates and the associated standard error with respect to the observed value. (5) Repeat steps 1 to 4 for all the 30 households. (6) Use paired *t*-tests to test for the difference between the simulation results and the observed fuelwood consumption quantities for all these 30 households.

**Model validation**

The independent data from the 15 households that had not been employed for model development were used to validate the model. We followed the same procedure used for model verification in Section "Model verification".

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**Sensitivity analysis**

The purpose of conducting a sensitivity analysis is to evaluate how the amount of fuelwood consumption responds to relatively small changes in different components of the model. This process could help us to identify the most sensitive components. Also, it serves as an alternative approach to model testing because unusual responses of the model caused by a small change in one component may indicate some potential errors in model structure or model parameterization. To measure the sensitivity, we employed the following sensitivity index (Jørgensen 1986):

$$S_x = (dX/X)/(dP/P) \qquad (16)$$

where $X$ is the value of dependent variable of interest and $P$ is the parameter value under normal conditions; $dX$ is the change in the dependent variable caused by $dP$, the change in parameter value. A larger $S_x$ indicates a higher sensitivity of the dependent variable (here fuelwood consumption) to the change in a specific component.

We conducted sensitivity analysis of fuelwood consumption in response to changes in socioeconomic factors. We gave each of the values of the selected socioeconomic components (e.g., potato/corn land, and transportation income, see Table 1.1) a 10% increase and examined the model responses (Table 1.1). We ran the model 50 times and calculated the average amount of fuelwood consumption under each of these conditions. Then we calculated the $S_x$ values based on equation 16.

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**Uncertainty analysis**

Another alternative for model testing is uncertainty analysis, which is defined as a way "to identify how model results vary with large variances in parameters" (Liu and Ashton 1998). When a parameter has too much uncertainty (or a wide range of values), uncertainty analysis can be employed to examine how a model responds to the changes in the associated parameter. We first examined how the annual amount of household consumption responds to changes in household size (from 2 to 10), assuming one senior person exists in all the cases. Then we did the same thing except that no senior exists in all the cases.

We also examined how annual amounts of household consumption respond to the interactions between household size and area of corn/potato land (the most sensitive economic component based on our sensitivity analysis). We chose four household sizes (2, 5, 7, 9 people, with one senior person each) and six levels of corn/potato area: 0.033 (ha, smallest area observed), 0.135, 0.270 (the average area from the 30 households), 0.405, 0.540, and 0.675 ha. For each of these 24 combinations (4 household sizes $\times$ 6 levels of land area), we ran 50 times and calculated the amounts of annual fuelwood consumption.

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## Results

### Verification and validation results

The model outcomes agreed well with the observations (Figures 1.9 and 1.10). The paired *t*-tests show that the model results matched well with the 30 observations ($p = 0.233$, $T = -1.220$) in model verification. The model outputs also agreed well with the 15 independent observations ($p = 0.1453$ $T = -1.550$) in model validation.

### Sensitivity analysis results

Amount of fuelwood consumption is not very sensitive to economic components except for two items, i.e., radish land and potato/corn land (Table 1.1). A negative relationship exists between amount of fuelwood consumption and the expense-related items, indicating more expenses in a household lead to less fuelwood consumption if other conditions keep unchanged. Furthermore, there is a positive relationship between amount of fuelwood consumption and income-related items, indicating higher incomes lead to more fuelwood consumption.

### Uncertainty analysis results

A household with a senior person consumes more fuelwood than that of the same size without a senior person, and this trend is not obvious when the household size is 2 (Fig. 11). The annual amount of fuelwood consumption for househc

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households with seniors increases with the household size; whereas the annual amount of fuelwood consumption for households without seniors shows a slight decline first as the household size increases from 2 to 4, and then increases from 4 to 10 (Fig. 11).

Amount of fuelwood consumption increases with the area of corn/potato land at each of the household sizes (Fig. 12). As corn/potato land increases, the differences among different household sizes becomes smaller and smaller. In the household with 2 people: as land area increases, the amount of fuelwood consumption increases at a faster speed in the region around 0.1 ha. It becomes higher than the amounts of fuelwood consumed by a household of 5 people from approximately 0.2 ha, and reaches the same amount of fuelwood consumed by a household of 7 people when the land area comes to approximately 0.65 ha.

## Conclusions and discussions

The age structure plays an important role in determining the household fuelwood use (Figure 1.11) regardless of other factors (e.g., household income) that have the potential to offset this influence. This result

can be explained from three perspectives: (1) households with aged people start heating earlier and end heating later each year (Section "Submodel FUELWOOD"), and thus need more fuelwood. (2) A household without a senior person, for instance, may have one more person of labor than that with a senior, and thus may result in more income. In section "Sensitivity analysis results", we mention

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mentioned the positive relationship between amount of fuelwood consumption and income level. In this sense, a household with a senior person should use less fuelwood due to lower income. (3) The ultimate amount of fuelwood consumption depends on which factor (age structure and more income) dominates under different conditions. Figure 1.11 shows that age structure plays a dominant role in determining amount of fuelwood consumption for households of 3 people or more. However, economic components may offset the differences of fuelwood consumption caused by age structure under some conditions. For instance, a 2-person household without a senior could have one more person of labor, thus could earn more income. As discussed before, this may slightly increase the amount of fuelwood consumption, thus decreasing the difference of amount of fuelwood consumption between a household with a senior and that without a senior.

The high sensitivity values for corn/potato land and radish land may result from the land-dependent life style (Figure 1.7). Due to the natural economy in the Reserve, farmers do not have enough opportunities to earn money from industrial and commercial activities. The most feasible way to increase income is to feed as many pigs as possible. By doing this, farmers can not only meet their own needs for meat consumption, but also can make money through selling their bacon to tourists and local restaurants. However, keeping more pigs requires more fodder to feed them and more fuelwood to cook the fodder. As mentioned above, local farmers' income sources are very limited, so they have to rely on their land instead of purchasing from market. Here the land-dependent life style results in the route of "more land—more fodder production—more pigs—more fodder cooking fuelwood".

The relatively obtuse responses from income- or expense-related components, consistent with this land-dependent life style, are explainable in terms of local farmers' subsistence demand. Farmers mostly depend on their land for subsistence, but they still have to trade for the necessary goods such as chemical fertilizers and land films (plastic films that keep the crop seedlings from the cold weather). So the impacts from economic status (incomes and expenses), though small, still exist. The positive relation between fuelwood consumption and the income-related items can be explained in two aspects: (1) higher income can increase their crop productivity by allowing the purchase of more chemical fertilizers, thus resulting in more fodder to feed pigs. In turn, more fuelwood is needed to cook the fodder. (2) Though higher income increases the ability to use electricity, most of the residents do not tend to do so if some cheaper or free substitutes (here fuelwood) are easily accessible and their income is not high enough to replace fuelwood with the electricity. In fact, our survey in summer 1999 showed that 78.18% of the 220 interviewees thought that the high price of electricity, with respect to their low income, was one of the barriers to switching from fuelwood to electricity for cooking and heating. Similarly, we can explain the negative relationship between fuelwood consumption and expense-related items because more expenses are equivalent to less income when other conditions stay unchanged.

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It may be unusual that the amount of fuelwood consumption falls slightly when the household size is small (from 2 to 4, Figure 1.11). This phenomenon can also be explained in terms of the land-dependent life style. When a relatively large area of cropland is fixed (0.27 ha for corn/potato and 0.146 ha for radish), a household of small size (e.g., 2 to 4 people) has a greater ability to grow more pig fodder because land for growing human food is much less than that for a household of large size. As a result, the fewer people, the more fuelwood for cooking pig fodder. But when the household size reaches a certain threshold (here 4 people), this trend will diminish because the additional people need more food, thus the land for growing pig fodder reduces drastically. As a result, household size plays a more important role in determining amount of fuelwood consumption, and amount of fuelwood consumption displays a positive relationship with household size.

The results of the uncertainty analysis (Figure 1.12) are also consistent with the above-mentioned land-dependent life style. When land area is small, people have no way to grow a large amount of fodder to feed pigs, thus the portion of fuelwood for cooking pig fodder is small, and the household size plays a dominant role in determining annual amount of fuelwood consumption. This is the reason why large differences are shown for households with small areas of corn/potato land. As the land area increases, amount of fuelwood consumption for cooking pig fodder takes a dominant role in determining total amount of fuelwood consumption, thus reducing the difference caused by household size. However, it is rare to see a small household (e.g., 2 people) with a large amount of cropland (e.g., 0.6 ha) and a large household (e.g., 9 people) with a very small amount of cropland (e.g., 0.1 ha). Our field data show that there is a positive relationship between the amount of cropland and the household size (Figure 1.13). This situation implies that a large household usually has more cropland and consumes more fuelwood than a small one does. In Fig. 12, the upper right region may represent fuelwood consumption by large households, whereas the lower left region may reflect fuelwood consumption by small households.

The significance of this model rests on the following aspects: (1) As a household-based model, its submodel *DEMOGRAPHY* follows the life-span of each individual in the household, thus can simulate the household population dynamics. (2) This model contains stochastic components in addition to those deterministic components, thus is able to simulate some random events at a given time, such as going to college. (3) The model provides a useful tool for analyzing interrelationships among various variables in the model, mostly based on field observations. Furthermore, it can be used to study the dynamics of fuelwood consumption over time. (4) This model can provide insights into how subsistence demands and social attitudes interact with each other and then impose additive impacts on panda habitat degradation. (5) This model provides a good foundation to evaluate the impacts of fuelwood consumption by all households across the entire Reserve.

**Figure Legend (Some of the figures are color images)**

Figure 1.1. The location and elevation of Wolong Nature Reserve in China.

Figure 1.2. The conceptual structure of PANDA_DEEM. The dashed arrow and star box are assumed impacts of fuelwood consumption on the giant panda habitat.

Figure 1.3. Age groups and the associated events in the life span of an individual.

Figure 1.4. Simulation of the death process.

Figure 1.5. Emigration and immigration through marriage.

Figure 1.6. Emigration through education.

Figure 1.7. Land-dependent life style of Wolong farmers. A large portion of their land (portion 1 and portion 2) is used to grow pig fodder.

Figure 1.8. Household potential incomes and expenses. See Section "Submodel ECONOMY" for variable definitions

Figure 1.9. Model verification--comparison between model predictions and field observations for fuelwood consumption of the 30 households in 1997. The field data associated with these 30 households were used for model construction.

Figure 1.10. Model validation--comparison between model predictions and field observations for fuelwood consumption of the 15 households in 1997. The field data associated with these 15 households were not used for model construction.

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Figure 1.11. The relation between amount of fuelwood consumption and household size. Household age structure has impact on fuelwood consumption.

Figure 1.12. The relationship between annual amount of fuelwood consumption and area of corn/potato land.

Figure 1.13. The relationship between cropland area and household size ($n=30$, $R^2=0.343$, $p=0.00068$).


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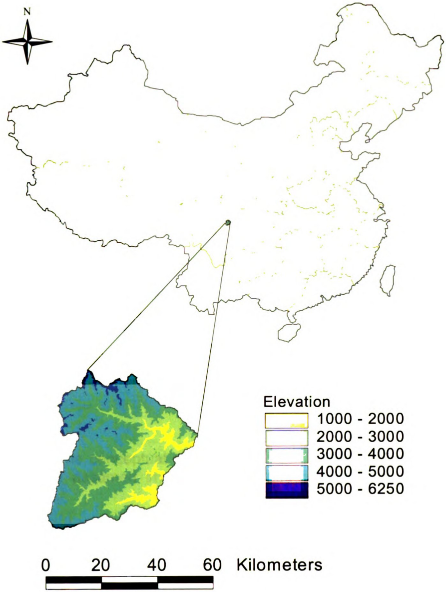


Figure 1.1. The location and elevation of Wolong Nature Reserve in China.

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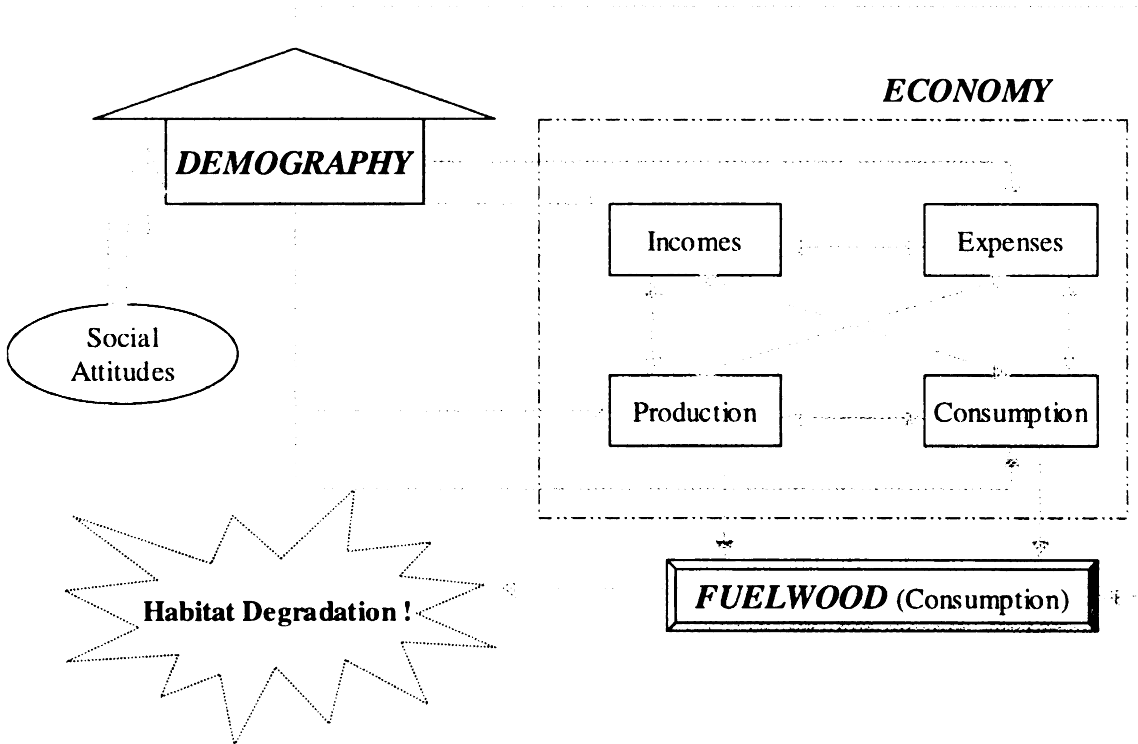



Figure 1.2. The conceptual structure of PANDA_DEEM. The dashed arrow and star box are assumed impacts of fuelwood consumption on the giant panda habitat.

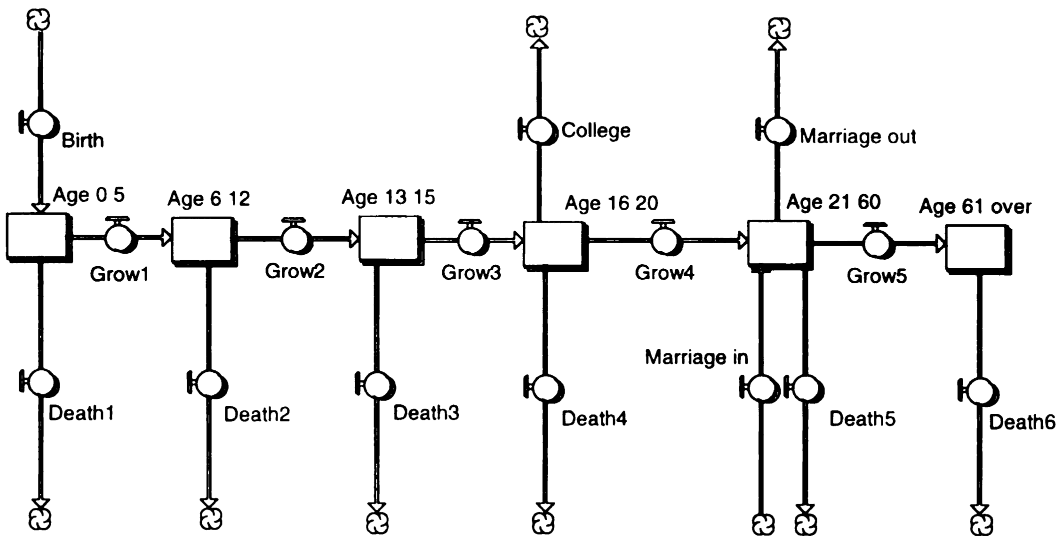
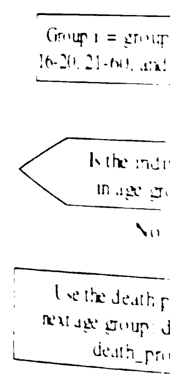



Figure 1.3. Age groups and the associated events in the life span of an individual.



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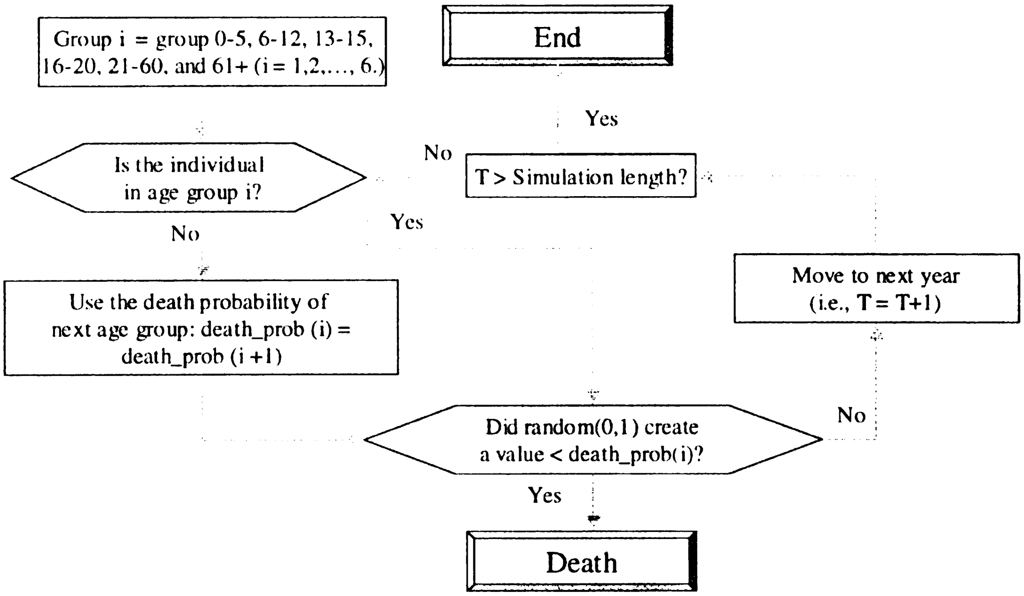


Figure 1.4. Simulation of the death process.


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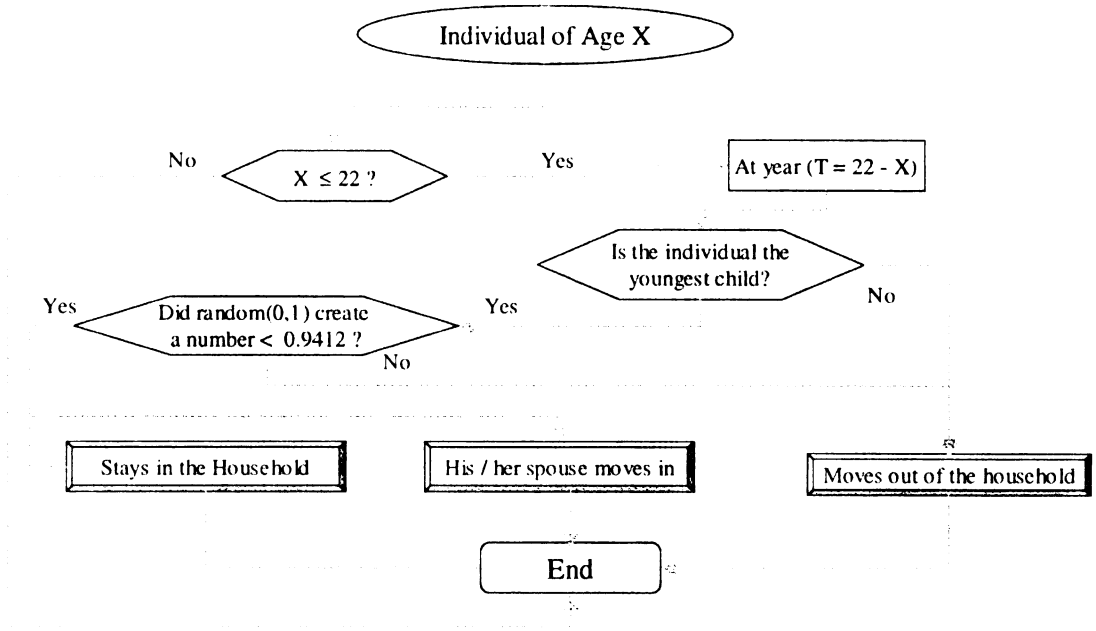
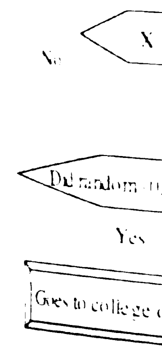



Figure 1.5. Emigration and immigration through marriage.

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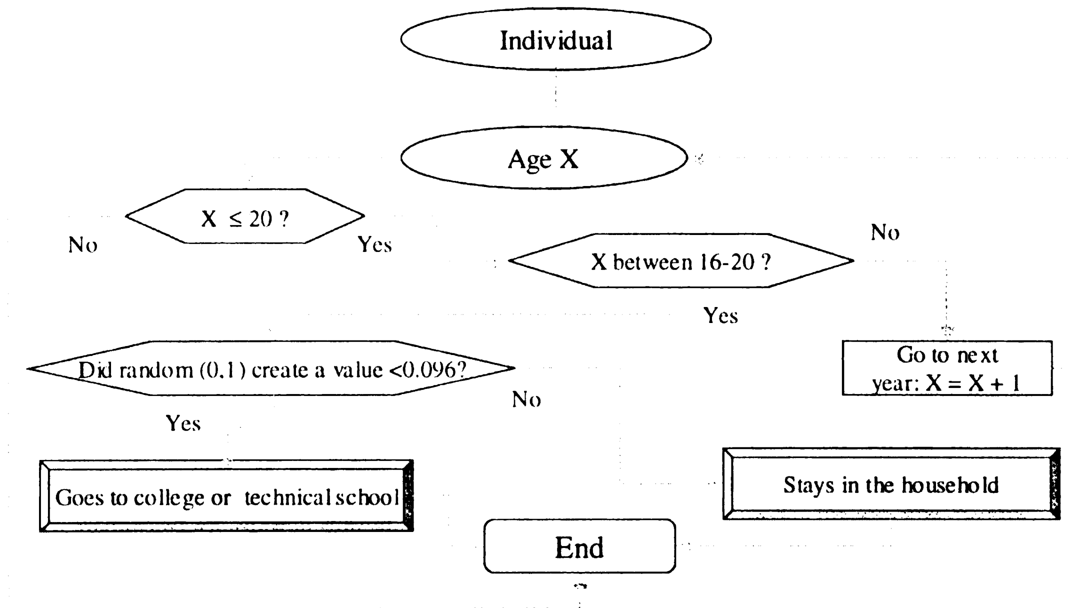
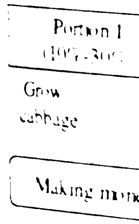



Figure 1.6. Emigration through education.

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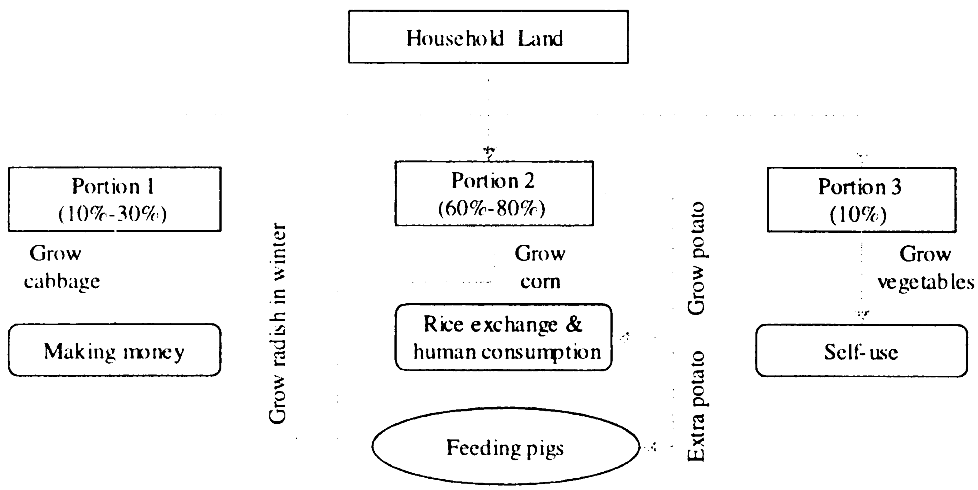
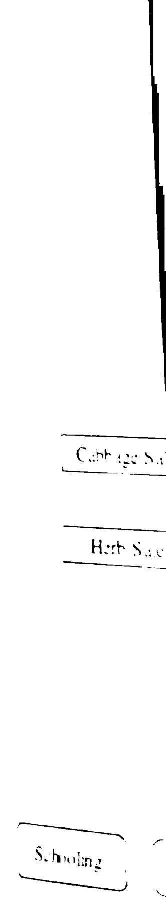



Figure 1.7. Land-dependent life style of Wolong farmers. A large portion of their land (portion 1 and portion 2) is used to grow pig fodder.

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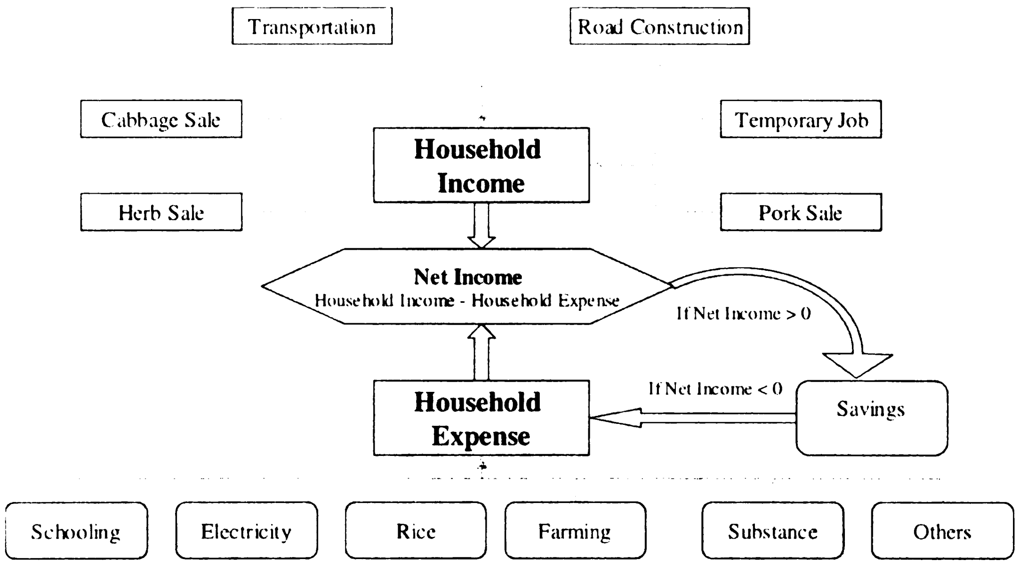
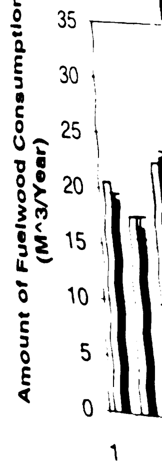



Figure 1.8. Household potential incomes and expenses. See Section “Submodel ECONOMY” for variable definitions

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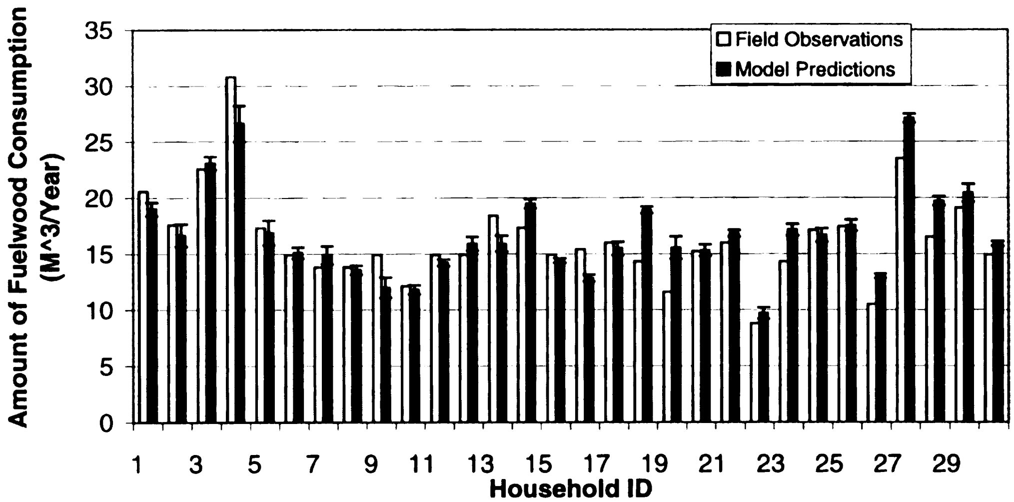
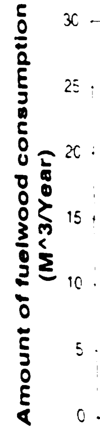



Figure 1.9. Model verification--comparison between model predictions and field observations for fuelwood consumption of the 30 households in 1997. The field data associated with these 30 households were used for model construction.

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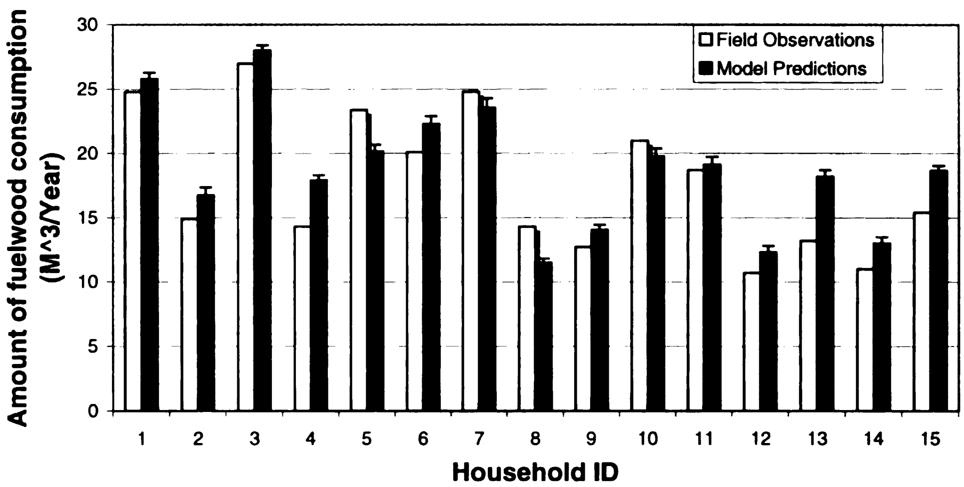


Figure 1.10. Model validation--comparison between model predictions and field observations for fuelwood consumption of the 15 households in 1997. The field data associated with these 15 households were not used for model construction.

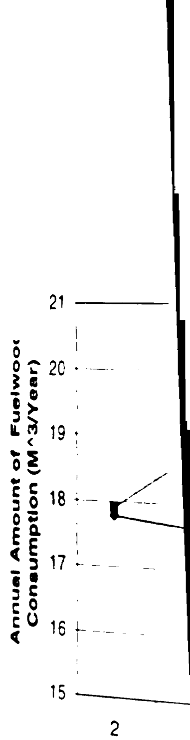


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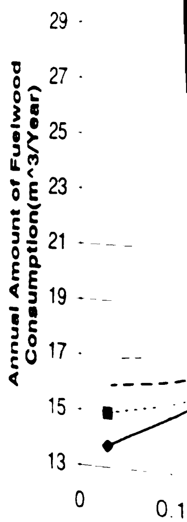
Figure 1.11. The relation between amount of fuelwood consumption and household size. Household age structure has impact on fuelwood consumption.

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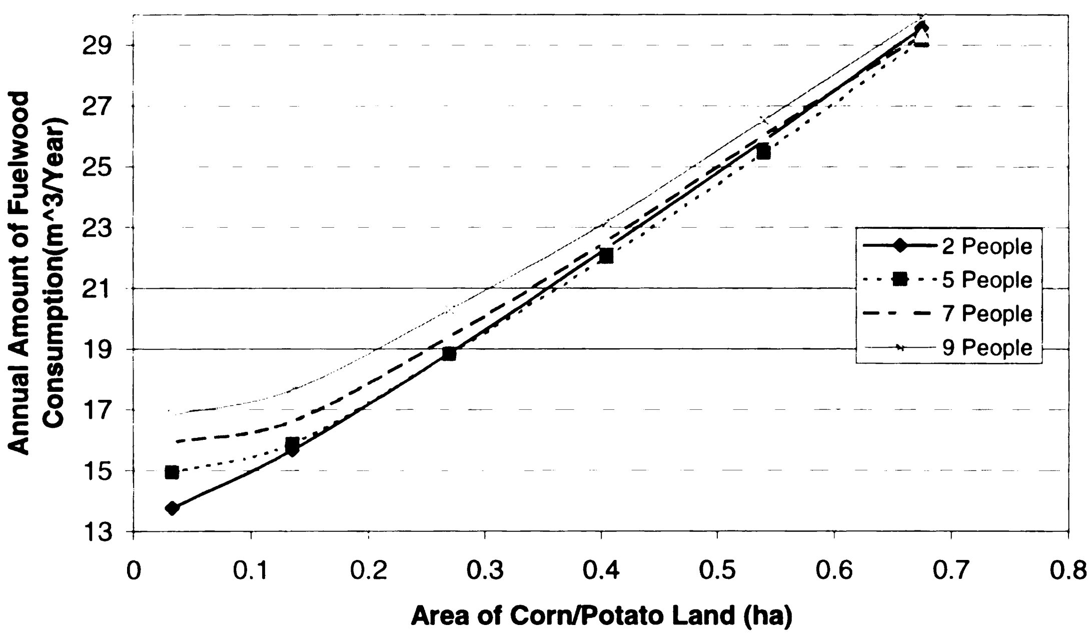


Figure 1.12. The relationship between annual amount of fuelwood consumption and area of corn/potato land.

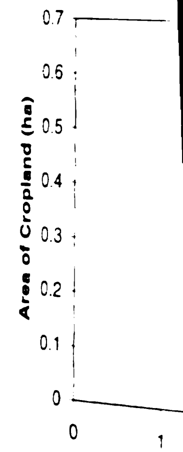


Figure 1.13. The

$R^2$=0.343, p=0.0

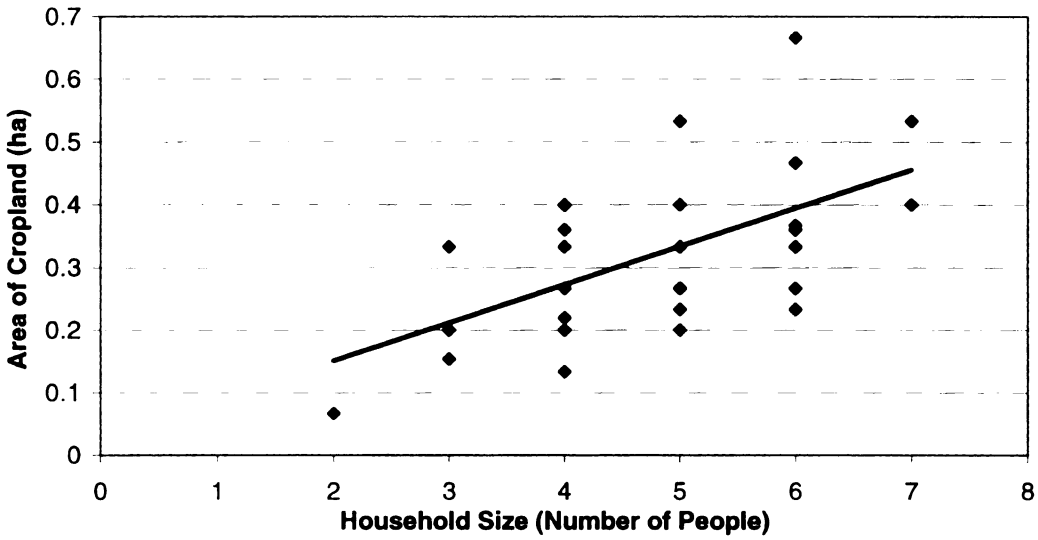


Figure 1.13. The relationship between cropland area and household size (n=30, $R^2$=0.343, p=0.00068).

Table 1.1.

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Table 1.1. Sensitivity indices of socioeconomic parameters

| Parameters | Initial value | Sensitivity Index |
|---|---|---|
| Elementary school expenses(Yuan/year) | 335 | -0.050 |
| Middle school expenses (Yuan/year) | 1842 | -0.060 |
| High school expenses(Yuan/year) | 5175 | -0.009 |
| Truck costs (Yuan) | 40000 | -0.012 |
| Rice price (Yuan/Kg) | 2.6 | -0.050 |
| Transportation income (Yuan/year) | 13250 | 0.002 |
| Road Income (Yuan/year) | 750 | 0.003 |
| Temporary job income (Yuan/year) | 1421.79 | 0.011 |
| Radish land (ha) | 0.146 | 0.144 |
| Potato/corn land (ha) | 0.27 | 0.227 |

Note: At the beginning of a simulation, a household had 5 people (9, 12, 34, 35, and 78 years old).

MODEL

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# CHAPTER 2

# MODELING THE CHOICE TO SWITCH FROM FUELWOOD TO ELECTRICITY: IMPLICATIONS FOR GIANT PANDA HABITAT CONSERVATION

Special gratitude to

Frank Lupi, Jianguo Liu, Marc A. Linderman,
and Jinyan Huang.

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## Abstract

Despite its status as a nature reserve, Wolong Nature Reserve (China) has experienced continued loss of giant panda habitat due to human activities such as fuelwood collection. Electricity, though available throughout Wolong, has not replaced fuelwood as an energy source. We used stated preference data obtained from in-person interviews to estimate a random utility model of the choice of adopting electricity for cooking and heating. Willingness to switch to electricity was explained by demographic and electricity factors (price, voltage, and outage frequency). In addition to price, non-price factors such as voltage and outage frequency significantly affect the demand. Thus, lowering electricity prices and increasing electricity quality would encourage local residents to switch from fuelwood to electricity and should be considered in the mix of policies to promote conservation of panda habitat.

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## Introduction

Dependence on fuelwood as the major energy source in rural areas of many developing countries has caused the so called "fuelwood crisis" (Dewees 1989). For example, around half of the world's population uses biomass fuels, accounting for 35% of the energy supplies in the developing countries (World Bank 1992). Asia, owing to its large population and the critical role that fuelwood plays in local life, has suffered dramatically from this crisis (Food and Agriculture Organization of the United Nations 1983). Characterized by an increasing demand for forest products, paralleled with a decreasing sustainable yield, the crisis has a range of negative consequences on the environment, including loss of biodiversity, deterioration of ecosystem services, soil erosion, increasing flooding, and global warming. A better understanding of the underlying mechanisms of this crisis (especially the determinants of rural household fuel substitution) is believed to be essential in relieving the crisis (Heltberg et al. 2000).

The fuelwood issue is also of significant interest in Wolong Nature Reserve (Figure 1.1), one of the largest giant panda reserves in China. The giant panda (*Ailuropoda melanoleuca*), considered a national treasure of China and of concern to people around the world, has suffered from serious habitat degradation that is characterized by decreasing habitat amounts and increasing habitat fragmentation (Liu et al. 1999). In response to this situation, China's central government has established 32 nature reserves in Sichuan, Sha'nxi, and

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Gansu provinces to protect critical habitats of giant pandas, totaling more than 16,000 $km^2$ (World Wildlife Fund 2001). Commercial timber logging is prohibited in these reserves, and local residents' timber forest consumption (e.g., timber for house construction, fuelwood use) has been restricted with regard to total amount, wood species, and collection sites (Reid and Jien 1999). Locally, special subsidies for cheaper chemical fertilizers and farming utensils are developed and provided to residents. Wolong Reserve Administration has also designated a number of areas as critical habitats and all human activities are prohibited. Furthermore, a special patrolling team has been set up to prevent poaching and illegal forest uses (Wolong Nature Reserve 1998).

Panda habitat degradation in Wolong Nature Reserve has been caused by deforestation, primarily for fuelwood collection (Liu et al. 2001a). Forests are a critical component of panda habitat, providing shelter and cover for this species. Moreover, pandas prefer to eat bamboo from forested areas – probably due to insufficient water content and decreased palatability of bamboo in areas without forest cover (Schaller et al. 1985). Recent work has shown that during the past two decades, annual fuelwood consumption has continued to increase from approximately 4,000 $m^3$ to 10,000 $m^3$, while panda habitat has been reduced by more than 20,000 ha (Liu et al. 1999). The panda population in Wolong declined from 145 animals in 1974 (Schaller 1985) to 72 animals in 1986 (China's Ministry of Forestry and World Wildlife Fund 1989). The decline was at least partially due to the loss of forest cover (Liu et al. 2001a), in addition to other factors such as bamboo flowering.

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Located in Sichuan (one of the most populated provinces in China), the reserve was designated in 1963 with an area of 200 $km^2$ and expanded to approximately 2,000 $km^2$ in 1975. The reserve contains a rural population of 4,320 people in 1998, corresponding to a total of 942 households. Households within the reserve rely mainly on growing corn, potatoes, and vegetables for subsistence, and they use fuelwood as their energy source for cooking (both human food and pig fodder) and heating in winter. Households within the reserve currently use electricity mainly for lighting and some electronic appliances, and only a small portion of them use electricity for cooking and heating.[1] Fuelwood in the reserve is not sold at the local market, and the farmers collect fuelwood mainly in winter for their own use in the following year. A recent study has found that residents in the reserve feel that in addition to the large amount of time and energy necessary for fuelwood collection, it is becoming increasingly difficult to collect fuelwood due to the shrinking forest area and the harsh topographical conditions—the elevations in the reserve range from 1,200 to 6,250 m, characterized by high mountains and deep valleys (Liu et al. 1999). The reserve administration has implemented many policies to restrict fuelwood collection, such as banning fuelwood collection in some key habitat areas and prohibiting some tree species from being harvested. Enforcement of these policies is difficult given the monitoring problems and the common property characteristics of the

[1] A recent survey has shown that all of the households have access to electricity, although most of them only use electricity for lighting and some electronic appliances such as televisions (Chapter 1). Crop residues and animal dung are not used as fuel because they are returned to cropland as fertilizers. Other types of energy sources such as biogas, kerosene, sun and wind power have not been used in Wolong (Chapter 1).

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forest. Despite the restrictions and difficulties of collecting fuelwood, the majority of local households continue to use fuelwood as their main energy source, even though electricity is available throughout the reserve.

The purpose of this paper is to examine the demand for electricity for cooking and heating within the reserve. In particular, we are interested in how price and non-price characteristics of electricity combine with other factors to influence the likelihood that a household will switch from fuelwood to electricity. We use stated preference data in a random utility choice model to quantify the determinants for the choice of switching to electricity as the energy source for cooking and heating purposes. The resulting model can be used to predict how alternative energy policies (i.e., electricity price and quality) can be manipulated to reduce human disturbance of panda habitat within the reserve.

Our study is significant for a number of reasons. First, panda biology and ecology have been extensively studied, but the mechanisms underlying humans' habitat-degrading activities (fuelwood collection is the key component) have not been adequately addressed, even though these aspects are crucially important for effective panda conservation (Liu et al. 1999). Our study is the first quantitative research on fuelwood substitution and electricity demand in Wolong. This research will facilitate local management of the reserve in a socially acceptable, economically feasible, and ecologically sound manner. Secondly, the framework and interview methods developed in this study would be useful for similar studies, especially those in developing countries where education, transportation, and telecommunication levels are low.

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## Conceptual framework

Lancaster's approach to consumer theory holds that utility is determined by the attributes of the goods rather than the goods per se (Lancaster 1971). Based on this theory, the stated preference data from our household interviews will be analyzed using discrete choice methods based on a random utility model (RUM) (McFadden 1974). The RUM is a well-established method for quantifying the preferences of individuals choosing a product (or service) from a finite set of alternatives. The simple operating assumption of the RUM is that the product chosen by a consumer yields the highest utility among all alternative products in a consumer's choice set. The model gets its name from the random terms used to characterize utility in recognition that researchers cannot measure all factors that are relevant to utility.

In our case, there are two alternatives in the choice set: (1) switch to electricity under the hypothetical situation, or (2) continue the current energy use pattern (predominantly fuelwood). Here fuelwood is the traditional and widely accepted energy source for the respondents, and they have a good understanding of the pros and cons of fuelwood consumption. For instance, they are aware that it takes time, and is getting more topographically and physically difficult, to collect and transport the fuelwood, but it saves money from limited budgets by using labor which is relatively abundant. In addition, respondents using fuelwood do not have to worry about power outages that are relatively common for ele

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common for electricity in the reserve. Electricity, though high in price and of mixed quality, is a familiar energy source for the respondents. All the households in the reserve have access to electricity and use it for lighting and electronic appliances. As for other potential energy substitutes such as biogas and sun/wind power, we excluded them from the choice set to avoid difficulties with their unfamiliar nature – they are not currently used within the reserve and respondents were not familiar with them.

Under the choice set thus obtained, we used a vector $\boldsymbol{x}_i$ to denote electricity price, outage levels, and voltage levels. The conditional indirect utility derived from alternative 1 by individual i (i =1,2...N), $U_i^1$, can be represented by the sum of an intercept $\alpha_i^1$, a deterministic component $\beta\boldsymbol{x}_i^1$, and an error term $\varepsilon_i^1$, as follows:

$$U_i^1 = \alpha_i^1 + \beta\boldsymbol{x}_i^1 + \varepsilon_i^1 \tag{1}$$

Faced with hypothetical and current situations, if the respondent views $U_i^1 > U_i^0$ (the utility derived from alternative 0 by individual i), then individual i will adopt the first choice (switch to electricity under the hypothetical condition).

Let $Y_i$ be the associated variable indicating individual i's choice of whether or not to switch to electricity (1 or 0), then the probability of switching is:

$$\begin{aligned} Prob.\ (Y_i = 1) &= Prob.\ (U_i^1 > U_i^0) = Prob\ \alpha_i^1 + \beta\boldsymbol{x}_i^1 + \varepsilon_i^1 > \alpha_i^0 + \beta\ \boldsymbol{x}_i^0 + \varepsilon_i^0) \\ &= Prob.\ [\beta\ (\boldsymbol{x}_i^1 - \boldsymbol{x}_i^0) + \alpha_i^1 - \alpha_i^0 + \varepsilon_i^1 - \varepsilon_i^0 > 0] \end{aligned} \tag{2}$$

where $U_i^1$ and $U_i^0$ represent the utilities that are associated with choices "switch to electricity under the hypothetical condition" and "continuation of current energy use pattern",

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use pattern", respectively. Vectors $\boldsymbol{x}_i^1$ and $\boldsymbol{x}_i^0$ represent the hypothetical and current electricity conditions (price, outage levels, and voltage levels), respectively. The terms $\alpha_i^1$ and $\alpha_i^0$ represent intercepts under these hypothetical and current conditions, $\beta$ is the parameter vector associated with $\boldsymbol{x}_i^1$ and $\boldsymbol{x}_i^0$. In addition, we seek to examine the extent to which other non-electricity factors, such as demographic variables, prices of possible substitutes to electricity, and geographic locations, can also explain inter-household differences in the switch to electricity, so these types of factors (described by the vector $\boldsymbol{z}_i$ with an associated parameter vector $\chi$) were also included. The common assumption that the error terms are distributed following a type I extreme value yields the familiar logit model (McFadden 1974). In our case, the probabilities take the following form,

$$\begin{aligned} Prob\,(Y_i{=}1 \mid \boldsymbol{x}_i, \boldsymbol{z}_i, \alpha, \beta, \chi) \\ &= \exp\,[\alpha + \beta\,(\boldsymbol{x}_i^1 - \boldsymbol{x}_i^0) + \chi\,\boldsymbol{z}_i] \,/\, [1 + \exp(\alpha + \beta\,(\boldsymbol{x}_i^1 - \boldsymbol{x}_i^0) + \chi\,\boldsymbol{z}_i)] \\ &= 1/[1 + \exp(-\alpha - \beta\,(\boldsymbol{x}_i^1 - \boldsymbol{x}_i^0) - \chi\,\boldsymbol{z}_i)] \qquad (3) \end{aligned}$$

Note from (3) that the final variables entering the logit model take the form of differences in variable levels except for the non-electricity factors $\boldsymbol{z}_i$.

## Methods

### Household Interviews

Our goal in this study was to estimate the demand for electricity under different conditions for electricity prices and quality, as well as relate the demand to demographic conditions. In our case, adequate market data spanning these conditions ar

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conditions are unavailable. For instance, the amount of electricity used by each household is not accurately recorded or not available in some areas, and the variation of electricity price is small. Stated preference techniques, sometimes referred to as contingent behavior, were used to overcome this problem. It is well reported that with these techniques researchers can design surveys to elicit preferences for goods with attributes that are not currently available in markets (Rubey and Lupi 1997). Debates on survey approaches, nevertheless, have continued for a long time—for example, the National Oceanographic and Atmospheric Administration (NOAA) panel has recommended face-to-face or telephone interviews for reliably eliciting stated preferences (Arrow et al. 1993). However, Dillman (1996) and Ethier et al. (2000) argued that the shortcomings of personal interviews are generally understated, while the problems of mail surveys are overstated. Of all these potential survey approaches, we chose face-to-face interviews because the low education levels of the respondents (only 4.2 years/person, Table 2.1) may limit their understanding of the questions if otherwise implemented. Another consideration for the survey mode was that most of the households do not have telephones. Moreover, because the reserve is a large rural area with a topographically difficult terrain, there are large postal delivery lags that render the local postal service unsatisfactory.

In the qualitative research stage of the project, preliminary interviews were conducted with 20 households in the summer of 1999. These interviews were designed to explore possible determinants of the switch to electricity; to test people's ability to make the choices; and to collect data to help us establish the levels fo

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levels for the attributes. We found that most of the local households indicated they could not afford electricity for cooking pig fodder and for heating because of the high amount of energy needed for these uses. In contrast, using electricity for lighting and appliances has a much smaller effect on the household budget and there is no readily available substitute for this energy. In addition, many households indicated that the electricity quality was not satisfactory for heating and cooking purposes, primarily characterized by low voltage and frequent outages during some seasons (especially in winter due to less water available for the hydropower stations) and in some areas (e.g., some villages in Wolong Township).

Based on the information obtained from the pre-interview, we finalized the design of the questionnaires and set up the discrete levels for the three continuous variables (price, outage, and voltage). The following seven levels were chosen for the electricity prices: 0, 0.02, 0.03, 0.04, 0.08, 0.16, and 0.25 Yuan/kwh.[2] The determination of these seven levels was based on the price information from the preliminary interviews – most of the respondents chose prices from 0.02 to 0.05 Yuan/kwh as thresholds for the switch, and some chose 0 as the prerequisite for the switch. We also included three higher prices with larger increments, 0.08, 0.16, and 0.25 Yuan/kwh, to test the willingness to switch under a broad range of prices. Seven levels, which are a relatively large number of levels when compared to many choice experiments in the literature,

[2] Yuan is a currency unit in China. $1 US = 8.3 Yuan in 1999.

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were chosen to provide a sufficient number of data points to test for any non-linear price effects. Electricity outage frequency was set at three levels (high, moderate, and seldom corresponding to 5 or more times per month, 2-4 times per month, and less than 2 times per month). Electricity voltage was also set at three levels (high, moderate, and low, corresponding to 200 or more volts, 150-200 volts, and less than 150 volts). Three sets of cards (two inches wide and three inches long for each) were prepared to show the electricity information to the respondent as follows: one set (seven cards) for the seven prices, one set (three cards) for the three outage levels, and one set (three cards) for the three voltage levels.

Our sampling frame was the 1996 Chinese statewide agricultural census list, which lists all households by villages. A village is a cluster of households that live geographically close to each other (there are six villages in the reserve). Our sample size was set at 220 (about 23% of the total number of households). The sample size reflects the tradeoff between our need for a robust sample and the limitations from our time, budget, and manpower. We used stratified sampling by proportionally drawing the 220 households from each of the six villages based on its size ($N_i$, i = 1, 2,...,6). Specifically, within village i, we coded all the households with numbers from 1 to $N_i$, and then randomly sampled $n_i$ (the sample size in village i) households from a total of $N_i$ households in village i.

To collect the stated preference data, we interviewed the head of each household in the summer of 1999 and recorded his/her age, gender, and education. Next, we collected household socioeconomic data, e.g., household expense i

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expense items in 1999 (then we summed over all the items for the annual total household expenses), educational levels, ages, genders of all household members, and so on. Respondents were then asked their current price, voltage level and outage frequency for electricity. In the section on electricity choice, the three sets of cards were placed face down in random order. We asked the respondent to pick up one card from the seven price cards; one card from the three electricity outage frequency cards, and lastly, one card from the three electricity voltage cards[3]. The question we asked (in Chinese) was: "under this condition, will you switch from fuelwood to electricity completely (for cooking, cooking pig fodder, and heating)?"

We had a 100% compliance rate in these interview sessions—this rate should not be surprising in Chinese rural cultures, where people like to be visited. Out of these 220 households, 28 households had problems in answering some of the questions—for example, they could not remember their current electricity price. Table 2.1 contains the demographic and socioeconomic profiles of the remaining 192 households available for the model estimation. The actual prices that local residents paid differed regionally because the hydropower stations within the reserve are run by different entities (companies, villages, or township governments) with different management goals, technical support teams, and

[3] The experimental design was thus determined by randomly combining the three electricity attributes. This approach is somewhat distinct from the main-effects designs that are common in choice experiments. The randomized design was chosen for both pragmatic and theoretical reasons. While main-effects design plans are parsimonious and relatively efficient designs for linear models, main-effects plans preclude the estimation of interactions between variables – effects we were interested in testing for. On a practical level, the randomized design used here was straightforward and easy to implement in the field.

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## Model specification and estimation

The data on the households' response to the question of whether they would switch to electricity were used to estimate a binary logit model (see equation 3). The variables used to explain the choices are a combination of electricity factors, locational factors, fuelwood transportation distance factors, and demographic factors. The variables used in the model are reported in column 1 of Table 2.2.[4] Corresponding to the $\mathbf{x}_i$'s in equations (1) to (3), there are three electricity-related variables in the model: price, outage frequency, and voltage (variables 5-10 in Table 2.2). Because the outage frequency and voltage variables take three discrete levels, each was recoded into two separate dummy variables for the respective low/seldom and moderate levels[5]. As indicated by equation (3), for each of the electricity variables, the differences in the attribute levels shown on the cards and the perceived current values of each attribute are entered as the variables in the binary logit model. In addition to the difference

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[4] We also evaluated two alternative models prior to our final model. The first includes only the demographic factors and provides evidence on the importance and validity of the electricity price and quality variables in explaining the stated choices. This limited model does a poor job in terms of overall model fit (Log L = -128.41) or parameter significance (only two factors are significant at the 10% level). A second model with only the electricity factors (price, voltage, outages) improves on the first model in terms of both overall fit (Log L = -90.68) and parameter significance (all are significant at 10% level, some at 5% and 1% levels). However, based on likelihood ratio tests, the model in Table 2 with the full set of variables is a significant improvement over both of the more limited models.

[5] The voltage level was expressed with two dummy variables, low voltage (V_L, 1 for low and 0 for otherwise) and moderate voltage (V_M, 1 for moderate and 0 for otherwise). Similarly, outage frequency was expressed by two dummy variables: seldom cutoff (C_S, 1 for seldom and 0 for otherwise) and moderate cutoff (C_M, 1 for moderate and 0 for otherwise). Two dummy variables were used to express the transportation distance factor: moderate distance (*trans_M*, 1 for moderate and 0 for otherwise) and short distance (*trans_L*, 1 for short and 0 for otherwise).

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between the hypothetical price and the current price ($P_1 - P_0$), the difference of the squared hypothetical price and squared current price ($P_1^2 - P_0^2$) enters as a variable to capture any non-linear effects of price changes. [6]

Several non-electricity variables were used in the analysis (items 1-4 and 11-13 in Table 2.2), corresponding to the $z_i$ in equation (3). Demographic variables include the respondents' age, gender, education (total years of schooling for the respondent), and household annual expenses. We chose household annual expenses as a proxy for annual income, in part due to the difficulties in collecting reliable information from the respondents about their incomes. The household expenses will roughly track incomes, although for our sample about 20% of the expenses go toward income producing activities such as farming. Thus, to some extent, the expenses variable reflects differences in incomes as well as potentially reflecting differences in the size of farming operations. The transportation distance variables, reflecting the distance between fuelwood collection sites and major roads, are included because they are proxies for the costs associated with fuelwood collection. The geographic location variable indicates which of the two townships within the reserve that the household resides in (*location*, 1 for Gengda Township and 0 for Wolong Township). Of the two townships that constitute the reserve, Gengda Township

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[6] Unlike the more common main-effects designs for choice models, our randomized design allowed us to test for interaction terms. To evaluate the effects of the interactions between the above variables, we tried the following terms: (1) hypothetical price ($P_1$) vs. voltage (*V_L* or *V_M*), (2) hypothetical price ($P_1$) vs. outage (*C_S or C_M*), (3) outage vs. voltage (e.g., *C_M*V_L*), and (4) price difference ($P_1 - P_0$) vs. outage difference ($C\_M_1 - C\_M_0$). The regression results show that these interactions improved the model fit very little. For instance, the model with $(P_1 - P_0)^*$ $(C\_S_1 - C\_S_0)$ only increased the LogL from -83.509 (Table 2) to -82.003. For model parsimony, we did not include these terms in the final model.

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has less forest cover than Wolong Township making it more difficult to collect fuelwood. Residents of Gengda also appear to be more likely to work or sell goods outside the reserve, which might raise the opportunity cost of time available for collecting fuelwood. The constant term represents females, high voltage, high outage frequency, high transportation distance, living in Wolong Township, and any other factors associated with alternative 1 (where 1 = "switch to electricity for cooking and heating").

Table 2.2 reports the parameter estimates, standard errors, significance levels, and the log likelihood value for our model. The performance of our model was further examined by using the empirical data on household's willingness to switch to electricity at different price levels. At price levels of 0, 0.02, 0.03, 0.04, 0.08, 0.16 and 0.25, the proportions of households that agreed to switch were 0.61, 0.86, 0.56, 0.59, 0.44, 0.18, and 0. The predicted probabilities of switching at these price levels were 0.80, 0.70, 0.65, 0.59, 0.37, 0.12, and 0.04, respectively.[7] The predicted probabilities at each price level are the average of the predicted values for the portion of the sample receiving that price level. A paired t test was preformed on the predicted and observed proportions resulting in t = - 0.10, p = 0.925, with d.f. = 6. This simple test implies that the null

[7] Note that these empirical frequencies are the averages across the choices for individuals receiving the respective prices and therefore include individuals who received various levels of the outage and voltage variables. For example, almost all of the individuals that were willing to switch at the prices (0.16 and 0.25 Yuan) that are higher than the current average of 0.13 Yuan drew cards with the high voltage level, the low cutoff frequency or both. Thus, improved quality influenced the choice. In addition, models without the squared term on prices tended to substantially overestimate the probability of switching at higher prices when compared to the empirical proportions.

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hypothesis (the difference between model predictions and the observed data is zero) cannot be rejected at the 5% level of significance.

## Results and discussions

As expected, price has a significant and negative effect on households' willingness to switch to electricity for cooking and heating (see Table 2.2). In addition, the squared term for the prices is significant and positive. Taken together, the results show that the choice probability decreases as price rises, and the rate of decrease falls as price rises.[8] Thus, the results indicate that demand is more price-sensitive at low prices than at higher prices than would be the case with just the linear effect. Also evident from Table 2.2 is the importance of the non-price electricity factors. Low voltage levels significantly reduce households' willingness to switch to electricity relative to moderate and high voltage levels. The moderate voltage level did not have a significant effect on choices. Lower outage frequencies (i.e., cutoff seldom, *C_S*, and cutoff moderate, *C_M*) significantly increase households' willingness to switch to electricity relative to high outage frequencies, with the seldom level having a larger effect than the moderate level. Taken together, the electricity price and quality variables provide clear and intuitive signals about households' energy decisions.

[8] The empirical curvature implies that at some prices the choice probability would no longer be decreasing in prices. However, this would not occur until price reached about 10 times the current price, which is well outside the relevant range of the data.

The signs of the other parameters in our model (Table 2.2) are consistent with our insights into the local situations. For instance, the annual expenditure, a proxy for household annual income and perhaps farm size, has a positive sign, indicating that higher income households are more likely to switch to electricity than those with less income. As expected, the sign for the low transportation indicates that the shorter the fuelwood transportation distance, the less likely the household is to switch to electricity, though this effect is only significant at the 10% level. The location factor has a positive sign, meaning the people in Gengda Township (coded as 1) are more likely to switch than those in Wolong Township (coded as 0) but the effect is not significant in our model. It was anticipated that this variable would have an impact for the following reasons: (1) there is less forest in Gengda, so the time and labor needed to collect fuelwood are higher; (2) the households in Gengda spend more time on commercial activities outside the reserve (e.g., transporting the local cabbage to surrounding cities such as Chengdu, the capital city of Sichuan province) and have a potentially higher opportunity cost of time.

Several implications of the results emerge. First, households' willingness to switch to electricity is clearly dependent on the cost. However, the results also reveal the important role that non-price characteristics of electricity might inadvertently play as barriers to electricity adoption. Thus, both electricity price and quality are relevant considerations in any energy policies aimed at conservation of giant panda habitat. Second, the results on the expenses variable suggest that investment in increasing income (e.g., through providing job

opportunities) of households within the reserve will likely reduce dependence on fuelwood. Third, the underlying data on current conditions reveal that the electricity quality in Gengda Township was better than in Wolong Township. The voltage and outage differences in Wolong and Gengda Townships suggest the potential for targeting approaches to improving electricity demand in differing parts of the reserve, e.g., more effort may need to be paid to increase voltage and lower the outage frequency in Wolong Township.

Figure 2.1 presents an illustration of the estimated demand curves under baseline conditions as well as under alternative assumptions on voltage levels and outage frequencies. For clearer illustration, we only present three curves corresponding to baseline, low voltage, and low outage scenarios. The curve for high outage is very close to that for low voltage, and the curves for normal voltage and moderate outage are very close to that for the baseline. The demand curves in Figure 2.1 were computed using the parameters specified in Table 2.2. For each of the curves, the switch probabilities were computed over the range of prices and were averaged across the 192 households. For each curve, the demographic and geographic variables were held at their initial levels. For the "baseline" curve, we computed the probabilities by holding constant the current electricity price ($P_0$) and varying $P_1$ (hypothetical price). For the "baseline" curve, the voltage and outage frequencies are held at their current values. The other curves in Figure 2.1 were computed similarly except that the voltage and outage frequencies in the hypothetical conditions were set at the indicated level. For example, the curve "Voltage Low" in Figure 2.1 was computed with the new voltage level set so that "$V\_L_1$=1" for all households.

Inspection of Figure 2.1 sheds light on the current situation for electricity demand and quality. The baseline demand curve is close to the curves that correspond to normal voltage and moderate outage, but higher than the two curves for low voltage and high outage—this implies that currently, the electricity voltage is not too bad, but the households in the reserve suffer from a moderate outage level—this is consistent with the survey data in Table 2.1. Another point that should be made is that the shift of the probability curves (or demand curves) in Figure 2.1 reflects people's responses towards electricity quality. When voltage is low or outage frequency is high, the associated demands (represented by the two curves for low voltage and high outage in Figure 2.1) are pulled down quite a lot, especially at the low price levels. When voltage is normal or the outage frequency is low, the demands have a comparatively larger increase, especially at low price levels. Again, a management implication is that one way to encourage more people to use electricity is to improve quality. Some quantitative figures may be more useful for local managers. For example, at price of 0.13 Yuan/kWh, the model predicts that an improvement in outage (from current frequency to the "seldom" level) will result in 6% more households switching to electricity (from 18% to 24%). However, if the outage frequency increases, around 8% of the households (around half of the current electricity users) will revert to dependence on fuelwood. If electricity quality (voltage and outage) remains unchanged in the baseline curve, a decrease in price from 0.13 to 0.10 will lead to about 10 % more households switching to electricity.

To further illuminate the willingness to switch to electricity for cooking and heating, we computed price elasticity at the average price of 0.13 Yuan/kWh by using equation (4):

$$Elasticity = \frac{\partial \pi}{\partial P_1} \times \frac{P_1}{\pi} = (1-\pi)(\beta_1 P_1 + 2\beta_2 P_1^{\,2}) \qquad (4)$$

where π is the probability of switching under the condition of interest, $P_1$ is the hypothetical price (0.13 here), $\beta_1$ (-28.1183) and $\beta_2$ (23.1005) are coefficients for ($P_1 - P_0$ ) and ($P_1^2 - P_0^2$) in our model, respectively (Table 2.2). Under the conditions corresponding to baseline, low voltage, normal voltage, low outage, moderate outage, and high outage levels, the elasticity values at the price of 0.13 are -1.67, -2.22, -2.00, -1.30, -1.58, and -2.00, averaging -1.80. This average elasticity of -1.8 means a 1% increase in price would lead to 1.8% decrease in electricity demand, or equivalently, 1.8% increase in fuelwood demand because no other energy sources could act as a substitute for electricity. Thus, the demand for electricity for heating and cooking in Wolong Nature Reserve is price elastic.

The price elasticity results and the price-demand relationship shown in Figure 2.1 have significant management implications. Because demand is so sensitive to price, any price change should be made with full consideration of the possible consequences. For instance, there was a rise in electricity price (an

increase around 0.05 Yuan/kWh) in Gengda Township in 1999; as a result, many farmers who had abandoned fuelwood consumption started to collect and use fuelwood again (Yang 1999, personal communication). Consequently, panda habitats must have been degraded to some extent.

Given the estimated model, we can predict the percentage of households switching to electricity under different electricity improvement regimes. These results can be translated into an estimate of the reduction in fuelwood collection. The average annual amount of fuelwood consumed by a household is 17.03 $m^3$/household/year (An et al. 2001). With this information, we could compute the amount of fuelwood that could be saved in the whole Wolong Nature Reserve through these quality improvement regimes by using equation (5):

$$Amount = \bar{\pi} \times \bar{s} \times N \qquad (5)$$

where $\bar{\pi}$ , $\bar{s}$ , and $N$ are average probability change under an electricity improvement regime (price, outage, or voltage change), the average annual amount of fuelwood consumed by a household, and total number of households in the reserve, respectively. Given $N$ = 942, $\bar{\pi}$ = 6%, and $\bar{s}$ = 17.03, a rough estimate of the total amount of fuelwood that could be saved per year just from a permanent outage improvement would be computed as 942 %X 0.06 % X 17.03 = 962.54 $m^3$. Given the amount of fuelwood saved through improved electricity quality or decreased price, reserve managers can analyze the impacts on the quantity and quality of panda habitat.

## Conclusions and future directions

Energy policies that stimulate electricity use in Wolong Nature Reserve will reduce dependence on fuelwood and will help protect dwindling giant panda habitat – critical habitat that is threatened by human disturbance despite its location within a nature reserve. Our model has helped explain why many people living in the Wolong Nature Reserve have not switched to electricity under the current conditions. The model provides insights into the quantitative interactions between electricity demand and different demographic and electricity management factors. The results indicate that the probability of switching to electricity was price elastic. Importantly, the results also show that electricity quality (outage frequency and voltage) have significant effects on adoption. For example, at the current average price of 0.13 Yuan/kWh, a 0.05 Yuan decrease in electricity rates would double the predicted number of households using electricity for cooking and heating. However, if this price decrease were accompanied by a shift to the high outage frequency, then we would not predict any change in households using electricity. Thus, the combined effect that any proposed energy policies would have on both electricity price and electricity quality should be considered when evaluating the potential effect on fuelwood use and panda habitat.[9]

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[9] Since immigration into the reserve is prohibited except through marriage, subsidizing electricity price and quality will not inadvertently induce households from outside the reserve to settle within the reserve.

To lower electricity price and increase the quality, the reserve administration will need to find financial support from various sources, such as central or provincial governments, and developing/managing local eco-tourism (already existent on small scale). Recently a "eco-hydropower plant" is under construction, and it is anticipated that upon completion this facility will provide cheaper and more reliable electricity to many local residents (An 2001, personal field observation). In addition, the reserve administration and Luneng Group have contracted for an eco-tourism program with an expected investment over 0.2 billion Yuan, and part of the revenue from this program would be used to subsidize electricity costs for local farmers (Mingcong Liu 2001, personal communication). These initial steps have shown that our suggestions are feasible and of interest to reserve managers.

There are several aspects of fuelwood use that may warrant further inquiry. First, some cultural or traditional perceptions may help to further explain the switch from fuelwood to electricity. For example, some individuals may prefer to use fuelwood due to the tradition of using fuelwood, or because he/she feels most comfortable/safe by using fuelwood, and so on. A better understanding of these other non-price factors would likely further improve the model. Such factors might also illuminate opportunities for panda conservation (e.g., education programs or electricity demonstration projects). Secondly, if we were able to increase our sample size, some of the existing non-electricity factors might have more explanatory power (e.g., the age and education factors). Nonetheless, the model performed well even with the current sample size.

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It may be that some households would only partially switch to electricity as their household characteristics change or as the electricity factors change. Similarly, some households might switch for some, but not all, energy uses (e.g., they may switch for heating and cooking human food, but not for cooking pig fodder). In contrast, we asked people whether they would completely switch to electricity for all cooking and heating uses under the hypothetical conditions. Based on our preliminary research and difficulties with this type of question in other settings, we did not attempt to collect stated preference data on the "quantity" dimension of the electricity choice. However, the success of the current research and the ability of the respondents to handle the discrete choice task suggest that it might be possible to ask respondents about partial shifts to electricity or to further distinguish among electricity uses. For example, the question might be posed in terms of the fraction of cooking and heating (e.g., 0, ¼, ½, ¾, 1) that would be done with electricity under different conditions rather than phrasing the question to directly elicit quantity in terms of kilowatt hours of electricity. Future research could be directed at determining whether such a stated preference format would also be successful.

The present study provides information on the potential effectiveness of electricity subsidies for protecting Panda habitat. However, this information is only part of what is needed to estimate the cost function for protecting panda habitat. Future efforts may seek to obtain data on the costs of different measures for reducing fuelwood collection (such as subsidizing electricity), along with ecological data on the associated impacts on panda habitat or populations,

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in order to predict the changes in panda habitat (in terms of amount and distribution) and population size given various monetary investments.

Of course, other alternatives may be complementary to our proposed measures. First, local residents' fuelwood stoves might be reformed to use fuelwood more efficiently. In the late 1980s, the reserve administration subsidized a stove-reformation program that proved unsuccessful because most farmers felt these stoves were inconvenient and hard to use in winter for cooking pig fodder (Zhou 1999, personal communication). Rather than solely considering energy-use efficiency, the stove-reformation program, if initiated in the future, needs to take into account easiness to use and capability to cook large amount of pig fodder in winter. Second, an education campaign that increases the awareness of the local residents of the increasing scarcity of forests and the importance of panda conservation might also reduce fuelwood use. The failure of the aforementioned stove-reformation program was partially due to the "tragedy of the commons"—if forests are viewed as unlimited and thus free, why do local residents bother to reform their stoves? Third, planting fuelwood-oriented trees in non-habitat areas might help to relieve the conflicting needs of forests between people and pandas. The reported success of a recently initiated statewide program called "Grain-to-Green" may provide evidence for this measure (Xu 2002). This program provides local farmers with free rice, wheat flour, tree seedlings, and a certain amount of cash given that they return a designated portion of their croplands and plant designated trees instead. Lastly, a more efficient and effective approach in the long run may be to invest on education of local fa

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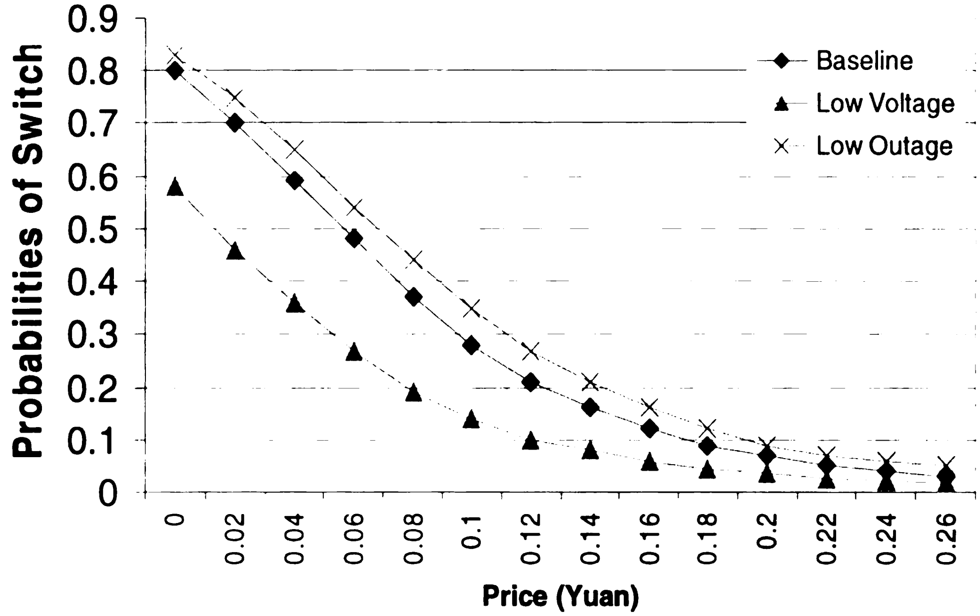
local farmers' children, encourage them go to colleges/technical schools, and find jobs/settle in cities (Liu et al. 2001b). Previous efforts to subsidize the relocation of local farmers have failed because many farmers returned to Wolong after living outside the reserve for some time. The local farmers, though unwilling to relocate themselves due to many reasons such as lack of land and inability to adapt to outside climate or culture, do hope their children have opportunities for higher education and jobs outside the reserve (Liu et al. 2001b). This is more effective insofar as relocated young people will have their offspring (children, grandchildren, and so on) outside the reserve. These experiences and our results indicate that subsidizing electricity prices and improving electricity quality, in combination with other approaches mentioned above, would benefit local residents while conserving giant pandas.

Figure legend

Figure 2.1 Probabilities of switch under different combinations of price, voltage, and outage levels.




2.1 Probabilities of switch under different combinations of price, voltage, and outage levels. The curve for high outage is very close to that for low voltage, and the curves for normal voltage and moderate outage are very close to those for the baseline. For clearer illustration, they are not displayed.

Table 2.1 Socioeconomic and Demographic Profiles of the Respondents

| **Variable** | N | Average | Std Dev |
|---|---|---|---|
| Age (Years) | 192 | 42.54 | 12.68 |
| Education (Schooling years) | 192 | 4.12 | 3.49 |
| Expense (Yuan/household/year) | 192 | 10802.97 | 11822.52 |
| Perceived Price (Yuan) | 192 | 0.13 | 0.10 |
| Perceived Outage Levels[a] | 192 | 1.61 | 0.76 |
| Perceived Voltage Levels[a] | 192 | 2.52 | 0.63 |

a. 1 for low, 2 for moderate, and 3 for high for both perceived outage levels and perceived voltage levels. (1 US $ = 8.3 Yuan in 1999).

Table 2.2 Results of the Logit Choice Model. The signs *, **, and *** represent significant at 10%, 5 %, and 1% level, respectively. The numbers in brackets are the standard errors. The subscripts 1 and 0 represent the hypothetical and current conditions, respectively.

| *Variable* | Code | Explanation | Parameter Estimate |
|---|---|---|---|
| **Intercept** | | | -2.3853** (1.0588) |
| *age* | 1 | Age of the respondent | 0.0215 (0.017) |
| *gender* | 2 | Gender of the respondent | -0.1727 (0.4476) |
| *education* | 3 | Schooling years of the respondent | 0.0552 (0.0666) |
| *Expense* | 4 | Annual household expense | 0.0533** (0.0225) |
| *prc_dif* | 5 | $P_1 - P_0$ | -28.1183*** (5.0239) |
| *squ_dif* | 6 | $P_1^2 - P_0^2$ | 23.1005*** (6.9912) |
| *V_L_dif* | 7 | $V\_L_1 - V\_L_0$. | -1.1863*** (0.4007) |
| V_M_dif | 8 | $V\_M_1 - V\_M_0$. | 0.3999 (0.3415) |
| C_S_dif | 9 | $C\_S_1 - C\_S_0$. | 1.3418*** (0.4095) |
| C_M_dif | 10 | $C\_M_1 - C\_M_0$. | 0.9719*** (0.3696) |
| *trans_L* | 11 | Low distance (1) & otherwise (0) | -1.2417* (0.8613) |
| *trans_M* | 12 | Moderate distance (1) & other wise (0) | -0.3363 (0.5498) |
| *location* | 13 | Gengda (1) & Wolong (0) | 0.6129 (0.5741) |
| LogL | | Overall model fit statistics | -83.509 |

# CHAPTER 3

# ADOLESCENTS' LEAVING PARENTAL HOME: PSYCHOSOCIAL CORRELATES AND IMPLICATIONS FOR CONSERVATION

Special gratitude to

Angela G. Mertig and Jianguo Liu

**Abstract**

To disclose the interplay between psychosocial antecedents of adolescents' decisions to leave their parental home in an ecologically sensitive region, we used structural equation modeling to analyze data from in-person interviews of members of 220 households in Wolong Nature Reserve for giant pandas (China). We further divided our data into two sub-samples by gender to test the hypothesis that model parameters differ for females and males. Our findings indicate that parental attitudes/behavior, peer behavior, and perceived availability of material/non-material resources play a critical role in adolescents' home-leaving decisions. This study demonstrates an important link between psychosocial phenomena and biodiversity conservation.

## Introduction

Adolescents leaving their parental homes has been viewed as a normal and natural phenomenon in Western societies (Baanders, 1996), as it signifies economic independence, personal responsibility, and emotional separation from parents (Goldscheieder and DaVanzo, 1985, Moore and Hotch, 1983, Stattin and Magnusson, 1996). Many studies of relevance to adolescents' decisions to leave their homes in Western societies have focused on general demographic trends (Mitchell et al., 1989), descriptions of the reasons for leaving one's parental home (Gierveld et al., 1991, Jones, 1995), timing of leaving one's parental home (Goldscheider and Goldscheider, 1993, Cooney and Mortimer, 1999), perceived consequences and social norms (Sebald, 1986), and distinct behavioral patterns related to gender, social class, race, ethnic origin, religious affiliation, and family structure (Goldscheider and Goldscheider, 1993, 1998, Cooney and Mortimer, 1999). However, the psychological causes and effects of leaving one's parental home, and especially their interplay, have seldom been quantitatively addressed (Mitchell et al., 1989). For instance, Gecas and Seff (1990) pointed out that most of the research on new household formation by adolescents was non-theoretical, descriptive, and explanatory, hence lacking rigorous models.

The paucity of rigorous models regarding adolescents' decisions to leave the parental home—especially within the context of a developing country—coupled with a need to understand how these decisions impact resource conservation issues, has prompted this particular study. Wolong Nature Reserve

(Figure 1.1), a prized panda reserve in China with observable conflicts between development and conversation goals, provides us an excellent site to address these concerns. Designated in 1963 with an area of 200 $km^2$ and expanded to 2,000 $km^2$ in 1975, Wolong Nature Reserve (Figure 1.1) is one of the largest reserves in China for conserving the giant panda (*Ailuropoda melanoleuca*), a national treasure of China and a pressing concern to people around the world. As a "flagship" reserve in China, Wolong has drawn domestic and international attention (Liu et al., 2001), garnering substantial governmental investment in and support for panda breeding/nursing research, anti-poaching patrolling, and commercial logging prohibitions. In addition, it has gained extensive technical and financial support from international organizations such as the World Wildlife Fund (Reid and Jien, 1999, World Wildlife Fund, 2001). Despite all these efforts, the past two decades have nonetheless witnessed a substantial decline in the reserve's panda population from 145 animals in 1974 (Giant Panda Expedition, 1974, Schaller, 1985) to 72 in 1986 (China's Ministry of Forestry and World Wildlife Fund, 1989). This decline in the panda population has been at least partially attributed to serious habitat degradation, which is believed to result from forest loss and fragmentation because forests are a critical component of panda habitat, providing food (i.e., bamboo), shelter, and cover (Schaller et al., 1985). Unlike many nature reserves, particularly those in the developed world, Wolong has a resident human population. Notably, there has been a continued increase in annual human fuelwood consumption in the reserve (from 4,000 $m^3$ in 1975 to

10,000 $m^3$ in 1998), accounting for most of the reduction of more than 20,000 ha of panda habitat in the past two decades (Liu et al., 1999a).

Paralleling this trend is an increase in human population in the reserve from 2,560 to 4,320 (a 69% increase) and an even more rapid escalation in the number of households from 421 to 942 (a 124% increase) between 1975 and 1998 (Liu et al., 1999a). The population increase can be explained by the fact that the famous “one child policy” does not apply to minority ethnic groups such as Tibetans, who make up the majority of reserve residents (Liu et al., 2001). The even greater rate of household increase, however, is due to the fact that young people in Wolong are now more likely to establish their own households, rather than live with their parents and grandparents under one roof, which in previous generations was a traditional norm in China (Wang, 2000, Liu et al., 2001). Even though it is reported that the past two decades have seen increasing temporary migration and even some inter-provincial (to coastal regions in particular) migration in China (e.g., Liang, 2001), the household registration system (known as Hukou) still exerts strict control on household migration, especially in undeveloped rural areas (e.g., Wu 1994, Wong and Huen 1998, Fan, 1999) like Wolong Nature Reserve, where the only major legal way for immigration is through marrying the people in Wolong. Though it is documented that some young adults from rural areas go to cities for temporary jobs (Xu and Tan, 2002), most of them remain in rural areas, relying on the land and local resources. This is also true for residents in Wolong, due to not only limitations imposed by the household registration system, but also other socioeconomic factors such as low levels of education and lack of technical skills to seek jobs outside the reserve (Liu et al., 2001).

These situations have made immigration and emigration inconsequential factors in determining household dynamics. Household division and formation within Wolong, rather than migration, is more relevant to household dynamics, which directly determines the demand for resources. Most households within the reserve live a rural lifestyle, characterized by growing corn, potatoes, and vegetables for subsistence, and using fuelwood as their energy source for cooking food (both for humans and pigs) and heating (An et al., 2001). Electricity is available across the reserve, but it is primarily used for lighting and some electronic appliances due to its relatively high price and inconsistent quality (An et al., 2002). Per capita consumption of resources is higher in smaller households than in larger households (Liu et al. 2003b). Given this lifestyle (energy use pattern in particular) and pattern of household dynamics, the increase in the number of households due to household division and formation in Wolong should be of more concern to conservation biologists than population size per se. It is the issue of resource use that links home leaving decisions and panda habitat conservation in the reserve.

Our goal was to quantitatively explain the behavior of adolescents' leaving their parental home using psychological, social, and demographic data. By understanding the process of new household formation, we will obtain three important pieces of information. First, we will gain insights into the psychosocial antecedents of leaving the parental home in an Eastern culture, especially in a

Chinese rural area, where the population is mostly composed of minority groups (Tibetans comprise approximately 75 % of the reserve population, Liu et al., 1999b). With counterpart studies available in Western societies (e.g., Sebald, 1986, Glick and Lin, 1986, Gierveld et al., 1991, Goldscheider and Goldscheider, 1993, Cooney and Mortimer, 1999), these insights may facilitate comparative studies on this topic. Second, our research could help local reserve managers find a socially acceptable and ecologically sound approach to controlling the increasing rate of household formation, thus reducing the habitat degradation caused by an increasing demand for household fuelwood. Finally, our research, characterized by using structural equation modeling with social survey data (see descriptions in the Methods section), will provide an innovative approach to studying the interrelationships between human population and the environment.

## Conceptual framework and hypotheses

A wealth of studies has shown that parents and peers, the most salient groups from whom adolescents learn norms and values, play a critical role in shaping adolescents' attitudes and influencing their final decisions (e.g., Britain, 1963, Larson, 1972, Montemayor, 1982, Sebald, 1986, Cooney and Mortimer, 1999). Although it is reported that these two groups (parents and peers) hold different and even confronting opinions on some issues (e.g., Horrocks, 1965, Bronfenbrenner, 1981), many researchers tend to agree that young people turn to different groups for different issues, questions, and needs. Indeed, parents and peers are complementary to each other, often referred to as "dual reference groups" (Montemayor, 1982, Sebald, 1986). Specifically, on the issue of leaving the parental home, research has shown that parents and peers have significant impacts on adolescents' decision-making process (Goldscheider and DaVanzo, 1985, Goldscheider and Goldscheider, 1993).

Aside from those with whom adolescents discuss leaving home, the phenomenon itself has been marked by a continual decrease in the average age at which adolescents choose to leave the home in both the United States (Goldscheider and DaVanzo, 1985, Goldscheider and Goldscheider, 1993) and Europe (Westoff, 1983, Van de Kaa, 1987, Gierveld, 1991). This trend towards younger ages has been attributed to a number of factors, all of which parallel economic growth: the "decline in traditional and religious authority," "universal education/employment of both genders," a culture focused on "personal gratification maximization," and "desire for autonomy, privacy, and independence" (Gierveld, 1991). It has also been observed that some adult children never even leave their parental home or later return home due to financial problems, unemployment, a sense of loneliness or isolation, and intense guilt over abandoning their parents (Clemens and Axelson, 1985, Goldscheider et al., 1999). Just as adolescents have reasons why they choose to leave or stay, so do the parents have reasons for promoting or discouraging leaving the parental home. Specifically, some parents encourage their children to remain/come home, even using "guilt producing" tactics. Adult children who live with their parents, termed "fledging adults" by Langway (1980), have both negative and positive influences on their parents and themselves. Positive influences include "more communication," "assistance in household maintenance," and "emotional closeness or companionship." Negative effects, which have seemingly drawn more attention, involve "parents' continuation to act in care-taking roles," "fledglings' continued behavior in immature and dependent ways," "deprivation of parents' freedom that they experienced before their children were born and which they are delighted to rediscover," "prevention from developing further interests," "inability to evaluate their marital relationship and resolve issues which may have been on the back burner," and so on (Clemens and Axelson, 1985).

Previous research has shown that individualism and autonomy are important psychosocial requisites, which can explain the "myself orientation" (Sebald, 1986) in many social activities such as career selection. Specifically, these requisites represent one of the major reasons for leaving the parental home (Gierveld et al., 1991). It has been noted that the decision to leave the parental home and its timing depend on many related issues as well, not solely on adolescents' (or parental) preferences. For instance, Blank and Torrechilla (1998) reported that the extended living arrangements (e.g., living with their parents or relatives within one home) among Latino immigrants in the USA result from their utilization of the elderly to care for young children, and sometimes their perceived responsibility to take care of the elderly who can no longer reside alone. Parental resources have also been found to be influential in determining adolescent choices. Gierveld et al. (1991) have classified parental resources into four categories: (1) transferable material resources—economic capital, e.g., money, property; (2) transferable non-material resources—parents' education, cultural and social capital; (3) non-transferable material resources—parents' taking care of house chores, supply and preparation of meals; and (4) non-transferable non-material resources—intra-family care, understanding, and community. Their research showed that transferable resources (categories 1 and 2) tend to hasten adolescents' decisions of leaving the parental home, while the non-transferable resources (categories 3 and 4) tend to delay their decisions.

There have been only a few studies on leaving the parental home within China. Current research suggests that the traditional lifestyle of many generations living under one roof has been declining (Wang, 2000, Liu et al., 2001), as the younger generations increasingly desire to have their own households. This desire has been seen as a challenge to parental authority, which is a traditional component of Confucian family ideology (Wang, 2000). Other research indicates that young Chinese adults are now more influenced by peer groups than by parents (China Adolescence Development Foundation, 1992). However, since research specific to China is so limited and what has been conducted shows growing similarities to the situation in more developed countries, our conceptual framework (Figure 3.1) is based primarily on findings from Western countries.

Using an important insight from the theory of Reasoned Action (Fishbein and Ajzen, 1975), namely that specific behavioral intentions are best predicted by attitudes germane to the behavior in question, our framework hypothesizes a direct link between a person's attitudes toward leaving the parental home and their intentions to do so. Prior research on the significant role of the "dual reference groups" suggests that parental behaviors, parental attitudes, peer behaviors, and peer attitudes should all have an impact on one's attitudes as well (this is similar to the notion of the subjective norm in the theory of Reasoned Action). Parents as well as peers influence how adolescents prioritize between two competing desires: the desire for privacy and autonomy on the one hand and the desire for companionship on the other hand (Gierveld et al., 1991). In this case, we also assert that parents' behavior and attitudes play a direct role in influencing behavioral intention. The lack of direct relationships between peers' attitudes and behaviors and the intention of leaving home in our model is due to important qualitative observations of the local situation being studied. Specifically, personal communication with local people indicated that they would not turn to peers for advice before making decisions. If a person suggests that another person leave his/her parental home or not, it is viewed as "meddling in other people's affairs" and thus "impolite." This is not to deny the influence of peers. These sorts of influences are considered to affect a person indirectly through the mediator of personal attitude.

We hypothesized that besides being directly impacted by the four antecedents mentioned above, adolescents' personal attitudes towards home-leaving behavior are impacted by a mediating psychological tendency, individualism. This accounts for a person's psychological demand for individualism and autonomy as suggested by Gierveld et al. (1991) and Sebald

(1986). This tendency toward individualism, formed and developed primarily at childhood, is in turn treated as a function of parents' behavior and attitudes. However, it may also be plausible that this tendency is jointly dependent on the behaviors and opinions of one's peers, indicated in hypothesis 2 below.

To account for the influence of parental resources as suggested by Gierveld et al. (1991), we hypothesized a direct effect of the perceived availability of transferable material resources (here: "Resource Availability") and of the perceived availability of transferable non-material resources (here: "Beneficial Effects") on attitudes toward leaving home. Likewise, we hypothesized a direct (albeit negative) effect of non-transferable resources (both material and non-material; here: "Adverse Effects") on personal attitudes.

Our hypothesis 1 is directly based on the above conceptual framework, represented by the ovals (latent variables) and the solid arrows connecting them (Figure 3.1). This hypothesis states that (1) a person's intention to leave the parental home is jointly determined by his/her personal attitude, attitude of his/her parents, and behavior of his/her parents. (2) Personal attitude toward leaving the parental home is impacted by parental behavior, parental attitudes, peer behavior, peer attitude, his/her personal tendency toward individualism, the perceived adverse and beneficial effects of leaving the parental home, and his/her perceived availability of resources. (3) A person's tendency toward individualism is influenced by his/her parents' behavior and attitude as well.

Research on leaving the parental home in Western countries has shown that a person seeking autonomy and independence often turns to his/her peers for reference and support (Sebald, 1986). Thus it may be reasonable to expect the tendency toward individualism to also be impacted by peers' attitude and behavior. The combination of these two relationships and the relationships stated in hypothesis 1 constitute our hypothesis 2. In our conceptual framework, these two additional relationships are represented by the two dashed arrows from peer behavior and peer attitude to individualism.

In order to further test the importance of transferable material resources in hastening the behavior of leaving one's parental home (Gierveld, 1991), we hypothesized that resource availability (i.e., transferable material resources) exerts a positive direct impact on the intention of leaving the parental home. In addition, we were also interested in testing whether perceived resource availability would have a direct impact on the tendency toward individualism, as it is believed in Chinese culture that hardships (including scarcity in material resources) accelerate the growth of a person's independence and maturity. Thus we developed a relationship from resource availability to individualism. These two relationships (dashed arrows with double dots between in Figure 3.1), together with the relationships mentioned in hypothesis 1 (solid arrows), form our hypothesis 3. Our last hypothesis (hypothesis 4) is a combination of all three hypotheses, representing an overall test of all of the aforementioned relationships.

In addition to the above hypotheses, we were interested in assessing whether one's gender makes a difference in determining how our conceptual framework works. It is well documented that males and females have different roles and behavior patterns in a number of social activities (e.g., Gierveld et al., 1991, Glick and Lin, 1986). For instance, males have traditionally been less parentally oriented than females, although this has recently been challenged by some researchers (e.g., Sebald, 1986), who have suggested that a trend of overall rejection of traditional gender stereotypes may account for an increasingly androgynous pattern in the decision-making of adolescents (e.g., Hughes and Gove, 1981). In order to address the possible gender-induced distinctions in our conceptual framework, we also ran separate analyses by gender.

## Methods

### Survey sample

We used in-person interviews to elicit the data needed for addressing the issue of leaving one's parental home. Local people's low educational levels (4.2 years of schooling per person, see An et al., 2002) and the inconvenient postal services made other survey modes untenable. Our sampling frame was the 1996 Agricultural Census list (Wolong Nature Reserve, 1996), which lists all households by villages (a village is a cluster of households that are geographically close to one another, and the reserve contains six such villages). In order to obtain insights into local people's concerns on this issue and develop our questionnaire, in the summer of 1999 we randomly selected 20 households and conducted pilot interviews. We asked the household heads a few open-ended questions regarding their own and their parents' attitudes towards this issue, perceived beneficial and adverse consequences, their perception of the appropriate time for leaving one's parental home, and so on. Having completed pilot interviews, we developed a more structured interview schedule for the next set of interviews. We used stratified sampling to select 220 households by proportionally drawing from each of the six villages based on its size ($N_i$, i = 1, 2,...,6). Specifically, within village i, we coded all the households with numbers from 1 to $N_i$, and then randomly sampled $n_i$ (the sample size in village i) households from a total of $N_i$ households in village i. Using this sampling procedure, we designated 220 out of the 942 households for interviews (approximately 23% of all the households in Wolong) during May–August of 1999. The sample size reflects the tradeoff between the limitations of our resources (i.e., time, money, and manpower) and the need for a relatively large sample. A large sample is important in Structural Equation Modeling because it is based on large-sample distribution theory (Raykov and Widaman, 1995, Jöreskog and Sörbom, 1996b). Within each selected household we chose an unmarried adult (18 years of age or older), if one was available. The reasons for this were: (1) only unmarried adolescents would have to decide whether or not to leave their parental home in the future; (2) 18 is usually the age at which people finish high school and take on full civil/criminal responsibilities in society under Chinese law. If household "A" did not have an unmarried 18+ year-old member, we switched to another household that did, household "B"—one member of which should be a child or sibling of the head (or his/her spouse) of household "A." Therefore, the 220 households could be classified into a subset where all the households had qualified young adolescents (hereafter called "direct group"), and another subset (comprised of household B's) in which siblings/children of the household heads (or their spouses) who lived independently were interviewed instead (hereafter referred to as "indirect group").

**Interviews**

Before each interview session started, we briefly explained to the interviewee who we were, the purpose of our research, how they had been selected, the estimated time of the interview, the confidentiality of the interview results, and the voluntary nature of the interview session. We interviewed a total of 220 young people, coming from both the direct and indirect groups. We had a 100% compliance rate in these interview sessions. This rate should not be surprising among residents of rural China where people usually enjoy being visited. Out of these 220 interviews, 203 had complete information on all of the variables and were used in our analysis.

**Measures**

Structural Equation Modeling (SEM) has been widely used in the social sciences (such as sociology and psychology) to study complex interdependent relationships between different latent variables, characterized by the fact that a latent variable can be both exogenous and endogenous in different equations (Bollen, 1989). A latent variable (also called construct) can be represented and measured by a number of indicators, i.e., questions designed to capture different aspects of the specific construct. Our constructs in the conceptual framework

(Figure 3.1) were measured using corresponding indicators, as listed in Table 3.1. While using multiple indicators for latent constructs increases the likelihood of achieving reliable conclusions (e.g., Bollen, 1989, Raykov and Widaman, 1995, Jöreskog and Sörbom, 1996b), in some situations it is not always possible to measure several indicators for each latent construct. In the absence of multiple indicators, SEM allows the researcher to use a single indicator and constrain its error variance to be zero to facilitate analysis (Mels, 2002, personal communication; Dr. Gerhard Mels is a senior programmer of LISREL and works as technical support in Scientific Software International, Inc.). This has been commonly used in practice, especially when the constructs to be measured deal with behaviors or intentions (e.g., Putte and Hoogstraten, 1997), since the margin of error in answering such questions should be very small. In some cases where we use multiple indicators, error variances were constrained to be zero since the original model resulted in a negative error variance. We used 2–3 indicators for each of our latent constructs except for three constructs related to a person's leaving intention and parental/peer behavior, where one indicator was used for each and the error variance was forced to be zero; the associated R squared would accordingly be 1 (Jöreskog and Sörbom, 1996c). The reliability of each indicator (without a constrained error variance) was measured by an index of R squared, ranging from 0 (unreliable) to 1(perfectly reliable). Below are measures of all constructs in our conceptual framework (Figure 3.1).

Table 3.1 lists our measures for the constructs in Figure 3.1. Some additional information not included in Table 3.1 is provided here in relation to the following constructs. (1) **Parental Behavior**: We used one dichotomous indicator to measure whether the interviewee's parents were living or had ever lived (if their grandparents were dead at the time of our interview) with their grandparent(s). We coded those answers indicating their grandparent's partial/seasonal stay with their parents (e.g., the siblings of their parents take turns caring for the grandparents) as "Yes." (2) **Peer Behavior:** We asked the interviewee to list four good friends and/or relatives whose opinions (regarding social activities) he/she most respected, and coded them as A, B, C, and D. Then we asked him/her whether each of these four friends was living (or had lived with, if the parent(s) died prior to our interview) with his/her parent(s). Those answers indicating partial/seasonal stay with their parents (e.g., the siblings take turns caring for their parents) were coded as "Yes." (3) **Resource Availability**: Our pilot interviews indicated that local people were very much concerned with land and wood because of the reserve's policy of restricting acquisition of additional materials for new home construction. Interestingly, money was not given as high a priority as we had expected. This is probably due to the fact that local residents mostly rely on locally available materials (stones and wood) for construction and neighbors' manpower through labor exchange with little or no cash payment. They only spend a limited amount of money buying construction materials such as tiles and electric meter, which cannot be produced by themselves. Therefore, we focused on measuring the availability of land and wood for this construct.

In relation to **Adverse Effects**, emotional closeness and ease of housework have been reported as important reasons for choosing to live with parents (e.g., Clemens and Axelson 1985, Gierveld et al. 1991). The findings in our pilot interviews corroborated this point of view. Loneliness/lack of intimacy with parents and increasing difficulty of housework (such as taking care of children, feeding pigs) were described as the major adverse consequences of leaving one's parental home. With regard to the **Beneficial Effects**, our pilot interviews showed that young adults tend to associate "more independence/ autonomy" and "more time and money for recreation activities" with leaving the parental home.

**Analyses**

The analyses consisted of four steps. First, in order to verify the utility of our indicators, a confirmatory factor analysis (CFA) was conducted on the seven exogenous constructs. CFA, in contrast to exploratory factor analysis, is characterized by determining relationships between latent constructs and their corresponding indicators in advance (Bollen, 1989). Second, a CFA was performed on the three endogenous constructs. Third, starting from our hypotheses mentioned earlier, we tested structural equation models (SEM) under these hypotheses. Last, we sorted our pooled data into two groups for males and females and conducted multi-group analyses based on the best-fitting model in the third step above. We used SIMPLIS to test the SEMs in all the steps. In addition to conforming to the t rule (Bollen, 1989), the statistical identification of our models was substantiated by the fact that (1) the models all converged; (2) no negative error variances occurred (after constraining problematic error variances to zero); and (3) there were no standardized estimates that exceeded unity (Gerhard Mels, 2002, personal communication).

In addition to traditional goodness of fit indices such as chi-square and p-values, we used a number of new indices suggested by Raykov and Widaman (1995). Among these indices, root mean square error of approximation (RMSEA) is considered to be less dependent on sample size. Previous research found the expected cross-validation index (ECVI) to be an important index in comparing several *a priori* theoretical models (Raykov and Widaman 1995). In summary, in order to make decisions among alternative models, we jointly considered the behavior of the following two groups of indices in addition to the typical $\chi^2$ and p-values: (1) Indices of model "badness": Root Mean Square Error of Approximation (RMSEA), Root Mean Square Residual (RMR), Expected Cross-Validation Index (ECVI), Non-centrality Parameter (NCP), $\chi^2$, and $\chi^2$/df. The lower the values for these indices, the better the model fits the data. (2) Indices of model "goodness": p-value, Goodness of Fit Index (GFI), and Adjusted Goodness of Fit Index (AGFI). The higher (closer to 1) the values for these indices, the better the model fits the data. For the definition of all these indices, see Jöreskog and Sörbom (1996b).

## Results

Our pilot interviews of 20 households showed that the perceived appropriate time for leaving the parental home was “after I get married,” “after the first child is born,” or “it depends on the number of siblings.” The possible reasons for leaving the parental home were “less conflict with brothers,” “more independence,” or “we have to leave because of too many siblings.” The possible reasons for not leaving the parental home were listed as “parents can help take care of our children,” “it depends on the availability of land,” “it depends on the availability of wood,” “depends on parents,” “children should look after parents,” or “need to care about relations with siblings and parents.” The beneficial consequences were deemed to be “freedom,” “more harmonious relations,” “more self reliance,” or “more time and money for entertainment,” while the adverse consequences were “lack of childcare,” “trouble doing housework,” “missing the parents,” or “parents lacking care.” The perceived attitudes of parents towards their children leaving the parental home were “it is a normal phenomenon, as a tree would have many branches when it grows up,” “depends on children,” or “at least one child should live with parents.”

Of the 203 respondents whose data were used for statistical analysis, 82 (40.39%) were females and 121 (59.61%) were males. The average age of these respondents was 22.1 years, ranging from 18 to 35 with a standard deviation of 2.2 years.

## CFA on latent variables

Overall the CFA on the seven exogenous constructs yielded a very good fit of the factor structure to the data. In terms of "badness" of fit, RMSEA = 0.031, RMR = 0.0631, ECVI = 0.815, NCP = 0.681, $\chi^2$ = 66.681, and $\chi2$ /df = 1.191 (df = 56, N = 203); in terms of goodness of fit, p = 0.156, GFI = 0.965, and AGFI = 0.934. The measurement model for exogenous constructs was deemed satisfactory for later analyses. The CFA on the three endogenous constructs yielded an even better overall fit: RMSEA = 0.000, RMR = 0.0135, ECVI = 0.129, NCP = 0.000, $\chi^2$ = 1.643 with, $\chi^2$ /df = 0.411 (df = 4, N = 203); along with p = 0.801, GFI = 0.999, and AGFI = 0.998. As with the first CFA model, the second CFA model for endogenous constructs was considered excellent for later analyses. Based on these two measurement models, we continued our hypothesis testing using the relationships discussed earlier in the Conceptual Framework and Hypotheses section. The measurement models tested here were incorporated in the model tests below.

## Hypothesis tests

Our structural equation modeling resulted in the following overall goodness of fit indices for models under Hypotheses 1–4, as in Table 3.2. As suggested by Raykov and Widaman (1995), it is safe to fail to reject an *a priori* model when $\chi^2$/df is less than 1.5, and RMSEA is less than 0.05. Considering these points, we rejected models 2 and 4, as they have large $\chi^2$/df and RMSEA values. Models 1 and 3 are close in terms of GFI, AGFI, and RMR, but differ in terms of $\chi^2$/df (less than 1.5 in model 3), RMSEA (less than 0.05 in model 3), and ECVI (1.533 in model 3 and 1.597 in model 1). In addition, model 3 has a $\chi^2$ reduction of 12.868 with a loss of only 2 degrees of freedom in comparison with model 1, corresponding to an observed p value of 0.003. This result indicates that the null hypothesis should be rejected in favor of the alternative—model 3 significantly improved the model fit compared to model 1. Bearing these facts in mind, we selected model 3 for further analysis regardless of model 3's relatively low p–value (0.002). Solely from the perspective of statistical acceptability of model-testing p–values in social science (greater than 0.05 or 0.01), even model 3 is not acceptable. But social scientists, especially when dealing with a large sample, rarely meet this standard because the null hypothesis being used tests how close the model is to the data. This is typically too rigid a standard with which to test a model's utility, as only slight variations between the model and the data can thereby lead to an overall rejection of the model. This is part of the reason to develop and use other model fit indices, as discussed in the Measures section (Bollen, 1989; Bollen and Long, 1993).

The following equations are used for model 3, where the coefficients $a_i$, $b_i$, and $c_i$ are reported in Table 3.3 and Figure 3.2.

Individualism = $a_1$×Parental Behavior + $a_2$×Parental Attitude + $a_3$×Resource Availability

Personal Attitude = $b_1\times$ Parental Behavior + $b_2\times$Parental Attitude + $b_3\times$Peer Behavior + $b_4\times$Peer Attitude + $b_5\times$ Resource Availability + b6×Adverse Effects + $b_7\times$ Beneficial Effects + b8×Individualism

Leaving Intention = $c_1\times$Parental Behavior + $c_2\times$Parental Attitude + $c_3\times$Resource Availability + $c_4\times$Personal Attitude

**Multi-group analysis**

As discussed above, the multi-group analysis was based on structural equations established in model 3. The results are shown in Table 3.4. The global (both groups as a whole) fit indices RMSEA, RMR, ECVI, and NCP, $\chi^2$ (df), $\chi^2$/df, and p–value (LISREL does not provide GFI and AGFI for global comparisons in multi-group analysis) were 0.032, 0.101, 2.788, 26.607, 322.607 (296), 1.090, and 0.138 respectively. Based on our earlier discussions on goodness of fit indices, the model fits are acceptable.

## Discussion

In this section, we will first discuss the possible mechanisms underlying the directional relationships identified in model 3. This discussion will be centered on the three endogenous constructs: individualism tendency (also an exogenous construct in relation to leaving intention), personal attitudes (also an exogenous construct in relation to leaving intention), and intention of leaving the parental home. Following this discussion will be our speculations on the gender-induced differences in the relationships.

**Intention of leaving the parental home**

Personal attitude, as expected, has direct and significant positive impacts on the intention of leaving one's parental home. The more a person favors leaving the parental home, the stronger is their intention to do so. Most interestingly, parents exert a significant negative impact on a person's intention: the coefficient from parental attitude to this intention is - 0.802, and that from parental behavior to this intention is - 0.153.

The reason for this negative relationship may be that these two generations hold opposite opinions on the issue of leaving the parental home. Surprisingly, it is the parents who are more supportive of their children leaving the parental home. On a scale of acceptance of children leaving home, ranging from 1 (strongly disagree) to 5 (strongly agree), parents registered an average score of 3.8, while adolescents averaged only 2.8. The following reasons could explain this phenomenon. First, Wolong is an undeveloped rural area in China with limited resources and few job opportunities. Within this context, young adults may be a little better off if they could reduce some daily expenses (e.g., for electricity) and labor (e.g., for collecting fuelwood) by staying with parents. Our previous research has shown that fuelwood consumption in a larger household is more efficient (Liu et al. unpublished data). Additionally, electricity expenses are a burden to local residents (An et al. 2001), and fuelwood collection has become increasingly difficult (Liu et al. 1999a). Under such conditions, it is natural for adolescents to slightly favor living with their parents while sacrificing some degree of autonomy. Second, many young couples indicated that it was very hard for them to handle housework (looking after children in particular) without assistance from parents. Lastly, from the parents' perspectives, they usually have many children (per couple) and may expect them to develop their own ways of making a living rather than being overly dependant on the parents.

The insignificant relationship between perceived resource availability and intention to leave the parental home, however, does not support what Gierveld et al. (1991) have found, i.e., that material resources would hasten the decision to leave the parental home. This lack of support could be related to two factors. First, property rights contribute in large part to the distinction. In Western societies, where private property rights have been legally defined and protected, properties such as land and houses can be inherited by children. In China, a farmer has only "rights of use" for the land he/she cultivates or occupies—and thus cannot sell or transfer it to other individuals, including family members. The wood on the associated land is similar to "common property," though Wolong has imposed some restrictions on harvesting wood (An et al. 2002). Under these conditions, a perceived high level of available resources may not be obtainable for future consumption. Lastly, even the households with the least amount of land assignments do not feel difficult to find enough land for building houses. Land was assigned to every household in the 1982 "land contracting and operation" reform (this reform was conducted in other rural areas of China a few years earlier, largely between 1978–1980) based on the household size at that time. Though household sizes may have changed since then, land for a typical household to build a few more houses may still be available and thus does not constitute a limiting factor. However, more insights may be obtained on this issue in our later multi-group analysis, in which the relationships between the intention and the perceived resource availability differ for males and females.

**Individualism tendency**

As we expected, both parentally related constructs, parental behavior and parental attitude, have significant positive impacts on the general psychological characteristic of individualism. In other words, the more parents favor the behavior of their children's leaving the parental home or the more they encourage it, the more likely it is for a person to have a tendency towards individualism. Perceived resource availability also plays an important role in shaping a person's individualism, though conversely: the more material resources that are available, the less independent or individualistic a person will be. This negative relationship between resource availability and individualism is consistent with Chinese culture, as discussed earlier in the Conceptual Framework and Hypotheses section: hardship facilitates earlier independence and greater autonomy. The lack of abundant material resources (land and wood in particular) could trigger a person to work hard and seek alternative material resources (e.g., using bricks, if affordable, for house construction rather than timber) and alternative non-material resources (pursuit of higher educations and jobs outside Wolong).

**Personal attitude**

Surprisingly, parental behavior and attitude do not exert direct significant impacts on personal attitudes towards leaving the parental home. Two reasons may account for this phenomenon. First, parental behavior and attitude impact their children primarily through shaping their children's psychological characters, such as a tendency towards individualism, as discussed earlier. The tendency thus formed has a more profound impact on their attitude towards a specific issue like leaving the parental home. This is reflected in the significant positive relationship from parental attitude to individualism (coefficient 0.461 with t value 4.356), and the positive relationship from individualism to personal attitude (coefficient 0.415 with a t value of 6.735). Second, as mentioned in the Conceptual Framework and Hypotheses section, young people in China have been increasingly challenging parental authority. This insignificant relationship between personal attitude and parental behavior/attitude could be a support for this conclusion. As to peers' impacts, we observed an insignificant relationship from peer behavior to personal attitude (coefficient 0.008 with t value of 0.100). But this relationship is significant in the multi-group analysis for both males and females and will be discussed later. The insignificant relationship from peer attitude to personal attitude (coefficient -0.091 with t value of -1.553) may signify that adolescents are concerned more about their own needs (as suggested by the significant relationship from individualism to personal attitude) and the deeds of their peers (there is a significant relationship from peer behavior to personal attitude in the forthcoming multi-group analysis), than what other people say.

The impact of perceived resource availability on personal attitude is weak, as indicated by the insignificant coefficient (0.091 with $t = 0.609$). This weakness can be understood from the perspective that as material resources provide conditions for some specific decision or behavior, they do not necessarily impact a person's attitudes or preferences directly. The negative relationship between adverse effects and personal attitude does provide support for Gierveld et al. (1991)'s findings, i.e., that non-transferable materials would impede this process. As listed in Table 3.1, the construct deals with loneliness/lack of intimacy and difficulty in handling housework, corresponding to non-transferable parental resources that were reported to slow down the decision to leave the parental home. The construct beneficial effects, measuring perceived independence and opportunities for more recreational activities in relation to the behavior of leaving the parental home, deals with a person's conformation to his/her surrounding environment and culture impacted by parents. Thus it could be viewed as a construct for transferable non-material resources, which should have been significantly positive (expediting the decision to leave the parental home) according to Gierveld et al. (1991). But it was found to be insignificant, with $t = 1.616$. A larger sample size may have caused this relationship to be statistically significant.

In accordance with our hypothesis that a greater tendency toward individualism would result in a greater intention to leave the parental home, there is a significant positive coefficient (0.415 with t = 6.735) from individualism tendency to personal attitude. Among all the significant relationships that are directed towards personal attitude, individualism tendency has the largest coefficient. Secondary to the tendency of individualism is adverse effects (- 0.321, t = 2.935). Peer Attitudes (- 0.196, t = -1.553) and beneficial effects (0.132, t = 1.616) are not significant at the 95% significance level, as we expected, but might have been so if a larger sample had been utilized. This suggests that a person's attitude towards leaving the parental home is primarily influenced by his/her own tendency toward individualism, but he/she also may have concerns about the effects (negative as well as positive) of this behavior.

**Differences resulting from gender**

Our multi-group analysis based on gender indicated that the coefficient (0.153) from parental behavior to individualism tendency in the female group was significant at the 90% level, while in the male group it was not. This significance suggests that women's individualism tendency is more impacted by parental behavior than is men's; this is typically reported as a "traditional gender stereotype" (Sebald, 1986). Wolong's economy is still characterized by traditional farming-oriented activities. Only since the 1980s have local residents started to receive frequent infusions of both products (e.g., chemical fertilizers, pesticides) and information (e.g., job opportunities, better farming techniques) from the outside world (An et al., 2001). Men have more opportunities to receive higher education or go out for temporary jobs than women do (Liu Mingcong 2001, personal communication). This context may provide a reasonable explanation for this finding. Paralleling this traditional trend, women show more concern about material resources (a coefficient of 0.491 from resource availability to leaving intention, with t = 2.619), and are more careful about adverse consequences (a coefficient of - 0.453 from adverse effects to personal attitude, with t = -2.469) when dealing with leaving the parental home.

Interestingly, personal attitude for men is significantly (at the 90% level) impacted by parental attitude (a coefficient of - 0.300 with t = -1.740), while that for women is not (t = 0.368). As discussed above, adolescents hold opposite attitudes on this issue compared to their parents, primarily due to a greater consideration of their ability to reduce daily expenses, fuelwood collection labor, and housework. This is particularly true for men because they take on many of these responsibilities. Therefore, it is understandable that men are more in favor of living with parents (in opposition to their parents' opinions) than women are. When the data are pooled, this negative trend is no longer significant with a coefficient equaling - 0.144 (t = - 0.915).

Another significant difference from what we have found in the pooled data is the direction and magnitude of peer behavior on personal attitude towards leaving the parental home. The coefficient for men is 0.214 with t = 2.566, implying that men are strongly impacted by their peers, whereas women have a coefficient of -0.239 with t = - 2.851, implying that they disagree with their peers' behavior on this issue. When the data are pooled, these opposite trends offset each other and show an insignificant relationship (a coefficient of 0.008 with t = 0.1, see Table 3.3).

The frequency distribution of the indicator for peer behavior may account for this discrepancy, given that male and female personal attitudes are similar. As discussed in Table 3.1, peer behavior was defined to be the number of close or respected friends and relatives (of four identified by the respondent) who lived/had lived independently. The distribution of this variable for women is bell-shaped, with an average around 2.1, indicating that among the four people whose opinions females respected, 2.1 people lived independently, and 1.9 lived with parents. The distribution for men is slightly skewed, with an average around 3.1, indicating that among the four people whose opinions males respected, 3.1 people lived independently, and only 0.9 lived with parents. This distinction may be due to the fact that men and women turn to different reference groups for the same concerns, i.e., women may tend to depend upon their elderly relatives of both genders (such as uncles and aunts; their aunts were less likely to live with parents) as their reference group, while men may tend to take their male friends and/or relatives of similar ages as their reference group, and most of these male friends/relatives live independently. Whatever lies behind this difference, our finding certainly warrants more research into the role of gender differentiation in home-leaving behavior.

## Summary and significance

In summary, we found that (1) a person's tendency toward individualism is primarily impacted by his/her parents and perceived resource availability, with little impact from peers. This finding is somewhat inconsistent with findings in Western countries. (2) A person's attitudes towards leaving the parental home (an issue more specific than individualism) are primarily shaped by his/her tendency toward individualism, and perceived adverse effects. This conclusion is consistent with the findings of Gierveld et al. (1991). Parental Attitudes and behavior have insignificant impacts on adolescents' attitudes, while peers' behaviors have opposite influences for men and women. (3) A person's intention to leave the parental home and live independently is more complex, depending on both his/her preferences/attitudes and the perceived resource availability for so doing (especially for women), as suggested by Gierveld et al. (1991). Different ideas exist between parents and adolescents: adolescents are more in favor of living with parents while parents are in less favor. (4) Non-transferable resources (material and non-material) tend to decrease a person's desire to leave the parental home, which is consistent with Gierveld et al.'s (1991) finding. Transferable resources have a more significant impact on women than on men. (5) Gender plays an important role in determining behavior patterns, as suggested in the literature (e.g., Hughes and Gove, 1981). Specifically, women in Wolong tend to rely more on parents and available resources when making decisions.

Clearly, the use of cross-sectional data limits our ability to determine exactly how these processes work and may mask the presence of reciprocal causation. For example, it is plausible that tendency toward individualism could be both a cause and an effect of leaving one's parental home. Hence, this research could be enhanced in the future by utilizing longitudinal measurement of home leaving intentions and behavior. Despite this, we believe our research has provided a statistically sophisticated and well-reasoned approach to this phenomenon, especially considering the dearth of research in this area.

Our research is significant in three respects. First, from the perspectives of sociology and demography, our research is consistent with many findings from Western countries, indicating cross-cultural similarities. For instance, a person's attitude towards leaving the parental home is negatively impacted by the perceived adverse effects, which, in this study, represents "non-transferable" resources found to hamper the decision to leave the parental home (Gierveld et al., 1991). But in some ways our findings are inconsistent with prior research in Western countries. For instance, Gierveld et al. (1991) found that transferable material resources would speed up the decision to leave the parental home, while our findings showed that transferable material resources do not have significant impacts on either personal attitude toward leaving the parental home or the intention to do so. Besides the possible reasons we provided in the Discussion section, other factors (such as the roles played by different cultures, ethnic groups, and genders in influencing different behavior patterns) may account for these inconsistencies. This highlights the need for comparative studies between Eastern and Western societies in these aspects.

Second, from the perspective of research methods, our research represents an innovative effort to link the study of human population with that of wildlife conservation (or natural resource conservation, in a more extensive sense). As indicated by Liu (2001), individual studies in ecology, biology, and human population (demographics in particular), though important and necessary, are not sufficient in dealing with problems that are inherently intertwined through many disciplines. Using structural equation modeling based on social survey data appears effective in eliciting the factors and their quantitative interrelationships that are of sociological, demographic, and ecological concern.

Last, from the perspective of panda habitat conservation, our findings can assist reserve managers to better understand what and how demographic/ psychosocial factors affect panda habitats. The bridge between this research and panda habitat is the escalating number of households relative to a more modest increase in human population size. On the one hand, our research identified what exogenous factors--in what directions (supporting or hampering), and to what extent--would determine a person's decision to leave the parental home. Over the entire landscape in Wolong, this implies that we could predict whether more (or fewer) new households would be initiated, given those exogenous factors. For instance, we observed a significant positive impact from perceived resource availability upon the intention of leaving the parental home for women. Therefore, it would be effective for the Reserve managers to place some restrictions on obtaining land and wood in order to reduce perceived resource availability and thus discourage new household formation. On the other hand, given the number of households with the specific demographic and socioeconomic features predicted from this research, we could predict how much fuelwood would be needed based on our household-based fuelwood demand model (An et al. 2001) and electricity demand model (An et al., 2002). We could utilize this household-based research to study the spatio-temporal dynamics of the households over the entire landscape if combined with geographic information systems (GIS) and demographic/ecological information in a spatially explicit context. This kind of spatially explicit dynamic model, capable of incorporating human population, ecology, and institutional factors, could be applied to study more complex issues, such as the overall interaction between a human population and its environment.


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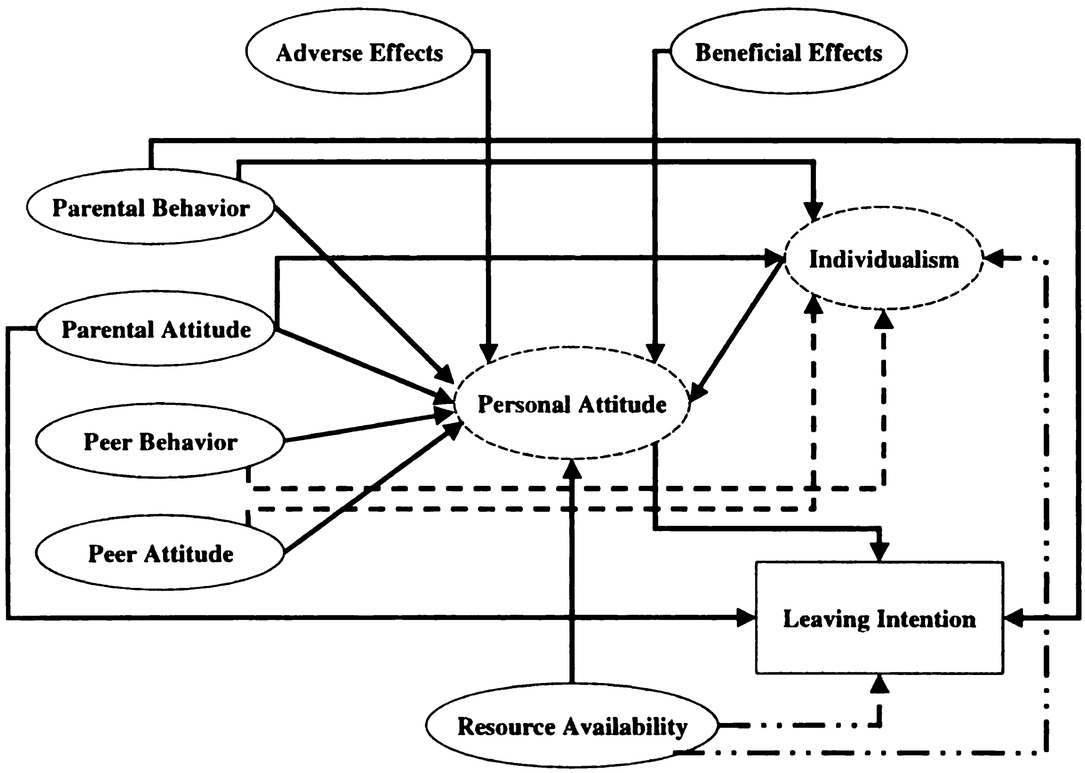
**Figure legends**

Figure 3.1. Conceptual Framework. The solid ovals are exogenous latent variables, and the dashed ovals are endogenous variables. Ovals at the start point of the arrow represent causes, and ovals at the end point of the arrow represent effects. The indicators for the constructs are excluded for clearer illustration. The solid arrows are relationships to be tested in hypothesis 1. The dashed arrows in conjunction with the solid arrows apply to hypothesis 2. The dashed arrows with double dots between, in conjunction with the solid arrows, apply to hypothesis 3. The square box represents the ultimate endogenous latent variable. A combination of all arrows constitutes hypothesis 4.

Figure 3.2. Illustration of the Structural Equations in Hypothesis 3 (Model 3). The solid arrows indicate relationships significant at the 95% confidence level, and the dashed arrows are insignificant at this level. The solid ovals indicate exogenous latent variables, and the dashed ovals represent endogenous latent variables. The numbers are effect coefficients for the associated relationships. Asterisks represent significance at the 95% confidence level. The square box represents the ultimate endogenous latent variable.

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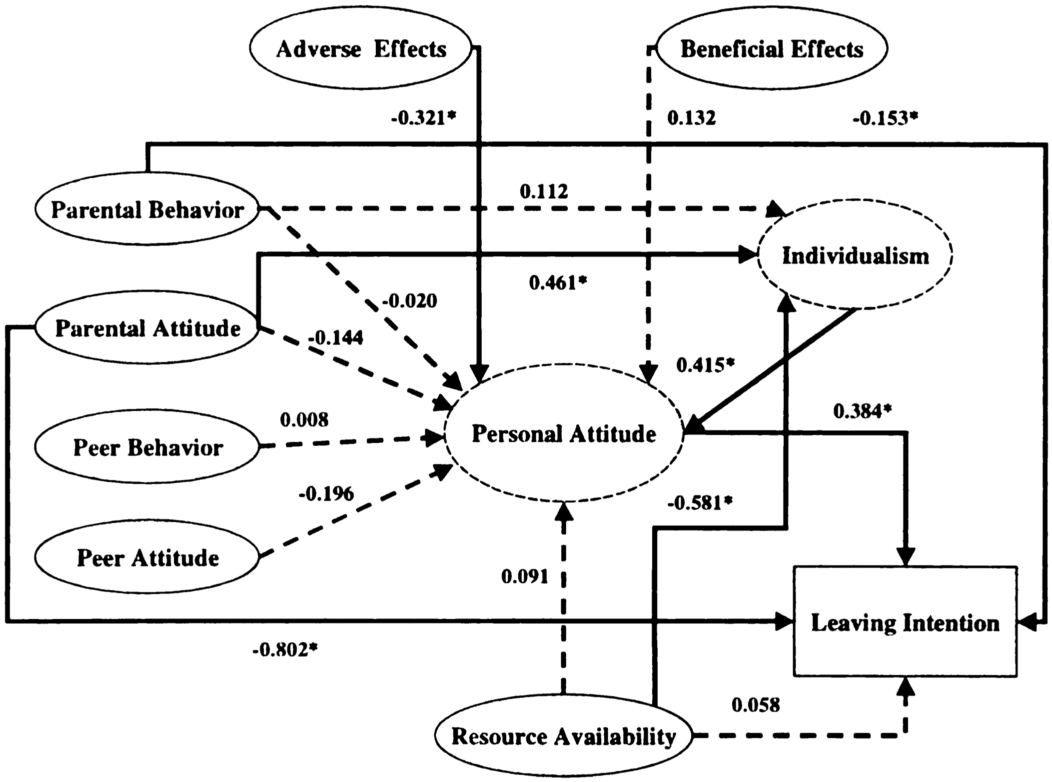


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Table 3.1 Latent variables and their indicators

| Constructs | Indicators/Question Wording | Coding | $R^2$ |
|---|---|---|---|
| Parental Behavior | Do/did your parents live with your grandparent(s)/ when they were alive? | 0-No;<br>1-Yes. | 1 |
| Parental Attitude | Do your parents agree with: "Children should leave parental home after they grow up"? | 1-strongly disagree,<br>3-unsure,<br>5-strongly agree. | 0.85 |
| | Do your parents agree with the following idea: "At least one child should live with his/her parents"? | 1-strongly agree,<br>3-unsure,<br>5-strongly disagree. | 1 |
| Peer Behavior | List four of your closest friends or relatives whose opinions you respect (names not needed). Does/did he/she live with his/her parents? | 1for no, 0 for yes. peerbhv = sum of answers for the four. | 1 |
| Peer Attitude | Do your good friends think that a person should live independently when he/she grows up? | 1-strongly disagree,<br>3-unsure,<br>5-strongly agree. | 0.497 |
| | Do the people around you favor leaving parental home after getting married? | 1-strongly disagree,<br>3-unsure<br>5-strongly agree. | 0.507 |
| | Do your relatives encourage you to leave your parental home when you are old enough? | 1-strongly agree,<br>3-unsure,<br>5-strongly disagree. | 0.335 |
| Resource Availability | I think it is __ to obtain land to build a new house if I want to | 1-very hard, 3-unsure, 5-very easy | 0.337 |
| | I think it is __ to obtain enough wood to build a new house if I want to | 1-very hard,<br>3-unsure,<br>5-very easy | 0.605 |
| Adverse Effects | How often do you think a person would feel loneliness/lack of communication with his/her parents when leaving parental home? | 1-never, 2-less often, 3-as before,<br>4- more often,<br>5- all the time. | 0.451 |
| | How often do you think a person would feel difficult to handle the housework without his/her parents' help? | The above one | 0.351 |
| | Do you agree the statement: "a person will feel more independence/less control from parents if he/she lives independently"? | 1-strongly disagree,<br>3-unsure,<br>5-strongly agree. | 0.717 |

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|---|---|---|---|
| Beneficial Effects | What do you think: "a person will be able to spend ____ money on recreation activities if he/she lives independently"? | 1-much less, 3-the same, 5-much more. | 0.331 |
| | What do you think: "a person will be able to spend ____ time on recreation activities if he/she lives independently"? | 1-much less, 3-the same, 5-much more. | 0.671 |
| Individualism | Do you agree: "I enjoy making household economic decisions (e.g., what crops to grow, find a temporary job in cities) by myself"? | 1-strongly disagree, 3-unsure, 5-strongly agree | 0.288 |
| | Do you agree: "I want to do whatever I view appropriate without having to listen to my parents"? | 1-strongly disagree, 3-unsure, 5-strongly agree | 0.576 |
| Personal Attitude | Do you agree: "Living separately is in general worse than living with parents because a person has to deal with many things he/she has not dealt with before"? | 1-strongly agree, 3-unsure, 5-strongly disagree | 1 |
| | Do you agree: "Living separately would make a person have the feeling of more maturity and freedom"? | 1-strongly disagree, 3-unsure, 5-strongly agree. | 0.744 |
| Leaving Intention | "How likely would you leave your parental home and set up your own home in the future (e.g., after marriage)?" | 1-never, 2-not so likely, 3-likely, 4-very likely, 5-for sure. | 1 |

Table 3.2 Goodness of fit indices of the structural equation models (N=203)*

| | RMSEA | RMR | ECVI | NCP | $\chi^2$(df) | $\chi^2$/df | p-value | GFI | AGFI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.050 | 0.066 | 1.597 | 59.566 | 176.566 (117) | 1.509 | 0.000 | 0.952 | 0.922 |
| 2 | 0.084 | 0.063 | 2.122 | 165.62 | 282.616 (117) | 2.416 | 0.000 | 0.957 | 0.931 |
| 3 | 0.046 | 0.062 | 1.533 | 48.698 | 163.698 (115) | 1.423 | 0.002 | 0.958 | 0.930 |
| 4 | 0.057 | 0.062 | 1.692 | 75.809 | 189.809 (114) | 1.665 | 0.000 | 0.958 | 0.930 |

Notes: RMSEA stands for Root Mean Square Error of Approximation, RMR for Root Mean Square Residual, ECVI for Expected Cross-Validation Index, NCP for estimated Non-Centrality Parameter, GFI for Goodness of Fit Index, and AGFI for Adjusted Goodness of Fit Index. For details of these indices, see Jöreskog KG, and Sörbom (1996b).

Table 3.3 Structural relationships under hypothesis 3.

| | | Endogenous Constructs | | |
|---|---|---|---|---|
| | | **Individualism** | **Personal Attitude** | **Leaving Intention** |
| **Exogenous Constructs (Predictors)** | Parental Behavior | 0.112 (1.847) | -0.020 (-0.303) | -0.153 (-2.035)* |
| | Parental Attitude | 0.461 (4.356) * | -0.144 (-0.915) | -0.802 (-4.772)* |
| | Peer Behavior | | 0.008 (0.100) | |
| | Peer Attitude | | -0.196 (-1.553) | |
| | Resource Availability | -0.581 (8.104)* | 0.091 (0.609) | 0.058 (0.359) |
| | Adverse Effects | | -0.321 (2.935)* | |
| | Beneficial Effects | | 0.132 (1.616) | |
| | Individualism | | 0.415 (6.735)* | |
| | Personal Attitude | | | 0.384 (5.268)* |

Table 3.4 Structural relationships for multi-group analysis.

| Exogenous Constructs (Predictors) | Endogenous Constructs: Individualism | | Personal Attitude | | Leaving Intention | |
|---|---|---|---|---|---|---|
| | Males | Females | Males | Females | Males | Females |
| Parental Behavior | 0.070 (0.977) | 0.153 (1.761) | 0.303 (0.354) | -0.127 (-1.273) | -0.148 (-1.480) | -0.169 (-1.424) |
| Parental Attitude | 0.432* (6.053) | 0.206 * (2.423) | -0.300 (-1.740) | 0.052 (0.369) | -0.527* (-5.387) | -0.513* (-4.224) |
| Peer Behavior | | | 0.214* (2.566) | -0.239* (-2.851) | | |
| Peer Attitude | | | -0.252 (-1.500) | -0.085 (-0.709) | | |
| Resource Availability | -0.402* (-3.227) | -1.061* (-5.493) | 0.102 (0.429) | 0.354 (1.419) | 0.074 (0.462) | 0.491* (2.619) |
| Adverse Effects | | | -0.116 (-0.686) | -0.453* (-2.469) | | |
| Beneficial Effects | | | 0.066 (0.589) | 0.174 (1.526) | | |
| Individualism | | | 0.570 * (4.836) | 0.542* (4.371) | | |
| Personal Attitude | | | | | 0.248* (3.088) | 0.454* (4.813) |

# CHAPTER 4

# AN AGENT-BASED SPATIAL MODEL FOR INTERDISCIPLINARY INTEGRATION: A CASE STUDY OF HOUSEHOLDS, PANDA HABITATS, AND FORESTS

Special gratitude to

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## Abstract

Traditional equation-based approaches to studying human-environment interactions often ignore individual-level information about the subjects under consideration, and thus result in great loss in prediction and explanation power in many situations. This paper reports on the development, implementation, and some results of an agent-based spatial model that avoids this problem, which is called Integrative Model for Simulating Household and Ecosystem Dynamics (IMSHED). This model simulates the impact of a growing rural population on the forests of the Wolong Nature Reserve for giant pandas (China). The local households follow a traditional rural lifestyle, in which fuelwood consumption has caused panda habitat degradation. By keeping track of the life history of individual persons and the dynamics of households, this model equips household agents with "knowledge" about themselves, other agents, and the environment, and allows individual agents to interact with each other and the environment through their activities in accordance with a set of artificial intelligence rules. The households and environment co-evolve over time and space, resulting in macroscopic human and habitat dynamics. Aside from helping conservation policy making, this approach may provide researchers with a useful tool to study how overall landscape patterns emerge as a result of actions of many agents by integrating interdisciplinary data across varying scales.

Keywords: agent-based modeling, spatial dynamics, households, socioeconomics and demographics, giant panda conservation

## Introduction

Human-environment interactions have drawn increasing attention to researchers with different backgrounds and research purposes. These types of studies have called for new approaches or methodologies to meet challenges that traditional analytic or state variable (called equation-based by some researchers such as Gulyás 2002) approaches alone cannot handle (Grimm 1999). The challenges generally fall under three broad categories: (1) the multifaceted nature of the system under consideration; (2) the heterogeneous structure and nonlinear relationships among various components of the system; and (3) integration of cross-scale (both spatial and temporal) data. Environmental modelers wrestling with these challenges typically turn to geographic information systems to assist in data management and modeling of spatially explicit variables.

Geographic information systems (GIS) are a powerful tool to capture, store, manipulate, and analyze spatial data, which has been extensively used in studying human-environment interactions. However, it is inherently static and cannot efficiently handle the temporal dynamics of many spatially heterogeneous phenomena. With the development of high-speed computers, agent-based modeling has shown great potential to successfully address the above challenges, especially when coupled with GIS. Agent-based modeling, similar to individual-based modeling in many ecological studies (e.g., Liu 1993, Liu and Ashton 1999) is a methodology that predicts or explains emergent higher-level phenomena by tracking the actions of multiple low-level "agents" that constitute or at least impact the system behavior at broader scales. Agents usually have some degree of self-awareness, intelligence, autonomous behavior, and knowledge of the environment and other agents as well; they can adjust their own actions in response to the environmental changes (Lim et al. 2002). The methodology underlying ABM is called "object-oriented programming" in computer science, and C++ and Java are the most popular coding languages.

Unlike procedural programming, where data and operations on these data are separated, object-oriented programming (OOP) groups operations and data (or behavior and state) into modular units called objects and lets the user combine objects into a structured network and form a useful program (Larkin and Wilson 1992). Simply put, an object (in our term, agent) is a concrete definition template (often observational unit) that inherits all the properties of its class, and has its own properties that distinguish it from other objects. Figure 4.1 (a) is an illustration of an object with operations called methods (Figure 4.1 (a)). This combination leads to the fact that the whole is greater the sum of its parts. Before building any objects, a class is usually defined as an abstract concept that contains the attributes (represented as variables such as height) and actions shared by a type of individuals or objects.

As such, one of the strengths of OOP is called modularity, a reduction in programming complexity such that different modules, relatively separated "parts" with different functional focuses, take care of different types of system functions without too great a programming burden at one time. Another strength of OOP is an increase in software reusability. When one piece of code (e.g., one method, one class) is defined and tested, it can be reused as many times as possible, which saves time for a big programming effort. Lastly, the strength of OOP lies in a property called "interface and implementation", which hides technical details inside the system surface, such as the parts in a clock (Figure 4.1 (b); NeXT Software, Inc. 1992) and how these parts interact with each other—this "implementation" feature makes the system (object) work well. A user-friendly interface, however, is designed to provide simple data input, output, and display functions such that other objects (or people) can call or use it—this "interface" feature makes information input and output easier and intuitive to understand. In addition this property allows for a varying degree of using an OOP-based model by users with different backgrounds and purposes. For instance, a scientist with programming experience may delve into details (e.g., objects, methods, and classes), while a novice may just want to try out different scenarios by adjusting a few options from the interface and keeping the details of implementation untouched.

A growing number of efforts to use this integrated approach (ABM plus GIS combo) have been made in the environmental modeling arena (e.g., Gimblett 2002, Jiang and Gimblett 2002), but few studies in studying human demographics and its impacts on the environment have been implemented. This integrated approach has the following potential in the domain of studying human-environment interactions: (1) capturing the individualistic properties of individual persons (households or other observation units), the basic agents in many human-environment studies; (2) representing and updating spatially heterogeneous data more efficiently; and (3) capturing the complex nonlinear mechanisms underlying many human-environment processes.

## Methods

### Study area

An excellent site to develop and test this integrated approach is Wolong Nature Reserve (China, Figure 1.1), for the following reasons: 1) it is recognized as a globally significant biodiversity conservation site; 2) much is known about giant panda biology; and 3) human impact on panda habitat is a serious problem in the reserve. Each is discussed in turn in the following paragraph.

First, established in 1975 (with an area of 2,000 $km^2$) for conserving the giant panda (*Ailuropoda melanoleuca*), the reserve is within one of the 25 global biodiversity hotspots (Myers et al. 2000), where over 2,200 animal/insect and over 4,000 plant species (Wolong Administration 1987) cohabit with the giant panda in a diverse biophysical environment. For instance, the elevations range from 1,200 to 6,250 m. Biodiversity has been increasingly viewed as an indicator of sustainable environment (Ehrlich and Wilson 1991). It is safe to say that a decreasing biodiversity implies a degrading environment with some ecosystem services negatively affected. Among varying levels (e.g., genetic, species, population, and ecosystem) in biodiversity studies, the habitat approach has proven to be significant based on the utter dependence of organisms on an appropriate environment (Ehrlich and Wilson 1991), especially considering findings from island biogeography—a famous example is the species-area relationship, i.e., $S=cA^z$, where S is the number of species that occur in a region with area A, and c and z are suitable constants (MacArthur and Wilson 1967). Thus conserving pandas in their habitats implies conserving local biodiversity and local environment. Second, extensive research efforts have been invested on giant panda biology, ecology, and habitat studies (e.g., Schaller 1985, Liu et al. 1999a). Thus we can use these results to build and test models. Third, though standing as a "flagship" reserve in China with substantial domestic and international financial (technical also in some cases) support, Wolong has a human settlement following a traditional rural lifestyle, in which fuelwood is used as the major energy source for cooking throughout the year and for heating in winter. This situation has made its biodiversity highly subject to human activities and policy changes. Last, the giant panda uses canopy cover as shelter, and understory bamboo for food sources (Schaller et al. 1985); local forests have been degraded in quantity and quality due to a rapid increase in rural population and an even more rapid increase in the number of households (Liu et al. 2003a)

Through our intensive fieldwork from 1998–2002, we have assembled a wealth of empirical data on both social and environmental factors and built a database in both Microsoft Access and GIS (ArcInfo). For instance, we have five time steps of high quality remotely sensed images between 1965 and 2000, a digital elevation model of 30×30 m resolution, and the coordinates of all the households in both Townships of Wolong and Gengda that constitute the reserve. These household coordinates were obtained by using global positioning system

(GPS) measurement and GIS extrapolation. We have the 2000 population census data of Wolong (the census was nationwide and implemented by all levels of governments), and have face-to-face interview data of 220 households (about 1000 households in total) regarding household economic status, social network (kinship relationship), and attitudes towards such issues as fertility.

In addition to this data collection effort, we have developed several behavioral and economic models for Wolong rural residents, including a household fuelwood annual demand model (An et al. 2001), an econometric model predicting electricity (an available substitute for fuelwood) demand based on a number of demographic and socioeconomic factors (An et al. 2002), as well as a structural equation model predicting the behavior of leaving parental home and household formation using a set of psychosocial factors such as peers' attitudes toward leaving parental homes, the perceived resource availability, and the individualism tendency (An et al. 2003).

**Conceptual model**

With an excellent study site and a wealth of data, we have developed an Integrative Model for Simulating Household and Ecosystem Dynamics (IMSHED). This model is concerned with characterizing household development through time and the consequent impact on forest resources comprising the panda reserve. Aside from providing a tool for local conservation decision-making, one major objective is to develop and test this integrative approach of agent-based modeling with GIS. The conceptual framework is illustrated in Figure 4.2. The layer of dashed households in the dashed box represents households in Wolong landscape at a past time, while the layer of solid ones represents households in the same landscape but at a later time. Our discussion below focuses on this layer.

First, all the existing households, symbolically called household A and household B, come from the past and will head into the future. This evolution includes many events: households may increase or decrease in size, dissolve, or relocate; new households may be initiated as individual persons go through their life history, the details of which are illustrated in Section "Demographic sub-model". Though the simulation and observational unit here is the household, individual information is contained implicitly as the household evolves. The formation of new households is determined or influenced by psychosocial factors (An et al. 2003). Second, at each snapshot over time, the fuelwood demand and the probability of switching from fuelwood to electricity for each household are determined by a number of socioeconomic and demographic factors (An et al. 2001, 2002). Third, the forests on the landscape, given no human interference, grow and die by themselves. Here the main concern is the type of species, growth rate, and total volume in each pixel. Last, the interactions between humans and the environment are realized through fuelwood collection, as shown by the two arrows in Figure 4.2. Any household, given a certain amount of fuelwood demand (the demand with the impact of electricity considered), goes to a certain pixel to cut fuelwood. Worth of mention are contextual factors that include policy, law, and geographical factors such as elevation and plant species.

They exert impacts on many processes such as household formation and demand for fuelwood and electricity.

**Major agents**

Major agents include individual persons, households, pixels (square grid cells representing homogenous units of the landscape), and some management agents helping us manage some objects or tasks (e.g., a list containing many agents of the same type). We only describe the major agents, starting from definitions of the corresponding classes. Management agents are usually abstract, not specific to this study (mostly some technical details in Java-Swarm), and space does not permit elaboration on them here.

- Person

This class includes attribute variables such as personal ID, age, ID of the household which she/he belongs to, education level, gender, personal ID's of his/her mother and father, his/her marital status, and an index that represents his/her role in the household in relation to the household head (for details see Section "Demographic sub-model"). Also, the Person class has a few variables associated with childbirth: birth plan (how many children this person would have), birth interval (number of years between two consecutive children), marriage year (the year the person gets married), birth year (the year the person gives birth to a child), and first-kid interval (the time between the marriage and the birth of her first baby). How these variables are used will be discussed in Section "Demographic sub-model".

The actions (called methods in Java) include: give birth, die, grow, marry, move out, move in, and cut fuelwood. Some other detailed actions (e.g., set the value for an attribute variable) specific to Java-Swarm programming are not discussed here.

- Household

This class includes attribute variables such as household ID (consistent with that defined in Person class), x coordinate, y coordinate, cropland area, household income, electricity price, outage level, voltage level, location of the household (Wolong Township for 0 and Gengda Township for 1; this is consistent with the dummy variable of location in the econometric model of An et al. 2002), distance of fuelwood collection, and probability of switching from fuelwood to electricity. All the variables needed for predicting electricity and fuelwood demand should be defined here because these demands are determined on the household level. Some variables such as the household head's education and age have been defined in Person class, and there is no need to define them again—all that need to do is to call the person that is head of this household.

The actions include establishing a new household, dissolving a current household (when the number of people who belong to this household is zero), or an increase or decrease in household size (i.e., number of people in a household). We assume that when a new household is established, the area within 90 m (a parameter that the modeler can change) around it has to be deforested and becomes non-habitat. This parameter is set in accordance with the resolution that will be mentioned in Section "Data collection, preparation, and integration". The rule of thumb is that it should be multiples of or at least equal to the finest resolution (more than one resolution is used in this study; see Section "Data collection, preparation, and integration") unless we only want the pixel where the household is located to be deforested.

- Pixel

Pixel class contains all the information that is necessary for simulation of landscape changes. It contains attribute variables such as x coordinate, y coordinate, elevation, slope, land cover type, forest age, and forest volume (for non-forest pixels, this volume is automatically set to zero).

The actions include land cover change (primarily from forest to non-forest), forest age increase, and volume growth (in forest pixels with tree species). We assume that forest volume reduction is primarily caused by fuelwood collection because other factors such as forest fires and timber cutting are rare nowadays (M Liu, personal communication).

**Data collection, preparation and integration**

- Spatial data

All the spatial data preparation is conducted in ESRI ArcGis and Erdas Imagine. Due to different resolution requirements for spatial data, we resample the 30×30 m digital elevation model (Linderman et al. 2003) to different resolutions of 90, 180, and 360 m. Based on the digital elevation model of the same resolution, we derive maps for slope in grid format. We also resample the land cover distribution map of 30 m resolution (Linderman et al. 2003) into maps with corresponding resolutions in Erdas Imagine. Among the land classes in the 30 m land cover map, we group the non-forest classes into one class and give it a code of 0 in the Swarm model. The remaining three classes are class 1 for deciduous forest, class 2 for conifer forest, and class 3 for mixed forest. All the elevation, slope, and land class data are converted to ASCII format prior to input to the Java-Swarm IMSHED model.

The volume of canopy trees in each pixel is class-specific based on the dominant tree species in that class: (1) Class 1 consists of *Facus, Quercus, Betula,* and *Populus*, and the volume range is 60 to 100 $m^3$/ha with ages ranging from 50 to 100 years old. (2) Class 2 consists of *Abies*, *Pinus*, and *Picea*, and the volume is from 200 to 400 $m^3$/ha with ages ranging from 40 to 110 years old. (3) Class 3 could be a mixture of any above species and some shrubs, we set its volume from 125 (the average of lower bounds of class 1 and 2) to 250 $m^3$/ha (the average of upper bounds of class 1 and 2); and the age is set to be from 40 to 90 years (Yang and Li 1992; Ouyang et al unpublished data; Linderman et al. 2003). However, due to intensive fuelwood collection and timber harvesting in the past, the surrounding areas of households have been greatly deforested. According to He et al. (2003, unpublished data), 89% of the local residents collected fuelwood in places within 4000 meters from their households in 1990s. So in the buffer areas within 4000 m (a parameter that the modeler can change) from existing households, we assume that the volumes are only 1/4 (another parameter that the modeler can change) of the areas outside this buffer (An, 1999 field observations; Zhou 2000, personal communication).

It is necessary to know the locations of households when deciding where to cut forest. The following steps are followed to obtain household spatial data and link these data to demographic and socioeconomic data. (1) In the summer of 2001, we measured a total of 59 households using a Trimble GPS unit with real time differential correction (Omnistar), where the accuracy was estimated to be within 2-3 meters. Four IKONOS satellite images (with 1 m resolution) that cover most of the area of Wolong with human settlements were also obtained. (2) We printed out a set of IKONOS maps with scales zoomed to a level such that locations of households in the maps were most easily identifiable. With such maps, we visited each of the local households with a few local researchers, and collected the socioeconomic and demographic information as described earlier (3) Using the coordinates of the 59 households as groundtruthing points, we georeferenced the four IKONOS images, and recorded the coordinates of all the identifiable households. (4) Using the names of household heads as ID, we linked the demographic and socioeconomic data with locational data (coordinates). For details of these processes, see Liu et al. (2003b).

- Demographic data

Our data used for model construction consist of the 1996 agricultural operation and contracting data (Wolong Administration 1997) and 2000 population census data (Wolong Administration 2000). All these individual-based data, arranged by household, include name, personal ID, ID of the household the person belongs to, gender, age, education, kinship relation to the household head, and so on. These data cover all people in the reserve.

Based on data in the kinship relation to the household head in the 2000 population census, we use an index system to represent these relations: each household head (either male or female) is given a relation index of 100.10, and his/her spouse 100.11. His/her siblings, if living in the same household, are given 100.20 (100.21 for spouse), 100.30 (100.31 for spouse), and so on. Since we have not found any household with more than 9 siblings living under one roof, and the current law does not allow any family to have more than 9 children in the future, this indexing method works well. An index of 90.10 is for father, 90.11 for mother, 90.20 for uncle/aunt and 90.21 for spouse if they live together, and so on. The children get 110.10 (110.11 for spouse), 110.20 (110.21 for spouse), and so on. If grandchildren are available, then we use 120.10 (120.11), 120.20 (120.21), and so on.

Comparing the individual data arranged on a household basis between 1996 and 2000, we calculate the number of males who migrated into Wolong through marriage, the number of females who migrated into Wolong through marriage, the number of males who migrated outside Wolong, and the number of females who migrated outside Wolong between 1996 and 2000. These numbers are 9, 40, 9, and 58, respectively. Using the number of males who migrated into Wolong through marriage divided by the average population size 4179 and the number of years (i.e., 5 years from 1996 to 2000), we have a rate of 0.00043, indicating that for each unmarried male person, the probability that he would move out of the reserve through marriage is 0.043%. Similarly, we calculated the other three rates of 0.19%, 0.043%, and 0.28%. These numbers are used later in Section "Demographic sub-model".

- Socioeconomic data

The 1996 and 2000 data sets as mentioned above also contain some socioeconomic data, such as the cropland area for each household, which is very important in determining household fuelwood demand (An et al 2001). The major socioeconomic data are from our interviews of a total of 220 households. The primary data include current electricity prices, outage frequencies, and voltage levels, which are used in computing the probability to switch from fuelwood to electricity. As described in An et al. (2002), the electricity prices and qualities vary over space, but are the same within villages. Because our interviews used a stratified random sample based on villages, we then can know the values for these variables of other households based on what villages they belong to.

Our home-leaving questions in the same interview sessions have obtained very useful information about what factors affect young adults' leaving parental home and establishing their own households after marriage. Those rules to be described later in Section "Demographic sub-model" about where to live after marriage are mainly based on these data.

**Demographic submodel**

All the individual-based data are entered into an Access database and exported into IMSHED using ASCII text file format. The model keeps track of the life history of individual persons (the objects of Person class) as follows: persons may give birth or be born, die, get married, move into or outside a household (subsequently into or outside the reserve in some cases) through marriage, and move outside a household (and thus outside the reserve in some cases). Households will correspondingly respond to these changes in terms of an increase or decrease in household size, formation of new households, or dissolution of some existing households.

- Education emigration and death

The death of a person is simulated through a random process. The likelihood of death for a person at a given year is in accordance with his/her age—0.00745 for 0-5 group, 0.0009 for 6-12 group, 0.00131 for 13-15 group, 0.00196 for 16-20 group, 0.00291 for 21-60 group, and 0.05354 for 60+ group.

These probabilities are calculated using mortality records of people at different ages between 1994 and 1996 (An et al. 2001). As the random number generator generates a number less than the mortality rate in accordance with the person's age, he/she dies (as person on the left in Figure 4.3), and his/her spouse (if she/he has one) changes her/his marital status to "without spouse" while switching to single male (or female) group; otherwise he/she survives.

If a person survives, the model checks his/her age. If the age is between 16 and 20 and the random number generator creates a number smaller than the rate of going to college for people in this age group (0.0192 for each of the five years; see An et al. 2001), then he/she goes to college and leaves the reserve permanently, otherwise the person remains in the household and moves to the next year. The rationale for doing so is that most (nearly 100%) of the young people who went to college have found a job in cities after graduation because cities have higher quality of life. In summary, these two processes are the same as those in An et al. (2001).

- Marriage and residence after marriage

Based on the age and marital status of a person, he/she is assigned to four groups (lists in Java): (1) young group for all less than 22 years old and unmarried people (males and females), (2) single male group for all single males over 22 years old, (3) single female group for all single females over 22 years old, (4) married group for all females and males who have spouses with them. For example, if a male in the young group reaches 22, he will move to the single male group; at some time if he gets married, he will move to the married group. However, if for some reason his spouse dies, he will move back to single male group again, and has the potential to get remarried, but the chance of doing so decreases as his age increases. We use the following way to decrease the probability of getting married as age increases: since the beginning marriage age is set to 22 years old, we assume that most of the single (first marriage) people will get married within 8 years by reaching 30 years old. We set 0.35 as the probability for a person between 22 and 30 to get married each year. So the probability that a person goes through all these 8 years without a first marriage is $0.65^8$, or 0.032—this small probability satisfies our assumption above. For a single person over 30 (most likely due to death of his/her spouse), we use the following equation to limit the probability:

$$\text{Rate of Marriage} = 0.35/(\text{age} - 30)^{0.4}.$$

So if a person is 31, he/she still has a probability of 0.35 to get married; if 32, then 0.26; if 33, then 0.23. ... These decreasing numbers are used to distinguish the marriage likelihood between different ages in relative sense. Under such a condition, a 60-year old person can only get married with a probability of $0.35/(60\text{-}30)^{0.4} = 0.090$, which is most likely true in most Chinese rural societies including Wolong based on our observations.

A very important component in simulating household demographic changes is to determine whether a newly married couple will initiate a new household or not. This is important in IMSHED because the efficiency of fuelwood consumption differs among households as household sizes change (Liu et al. 1999, 2003). Here the following situations are included in IMSHED:

(1) A local female brings an outside male into Wolong through marriage:

For a female in the single female group, if a random number generator creates a number smaller than the male_move_in rate of 0.019% (for how this number is derived, see the last paragraph in Section "Data collection, preparation, and integration"), then this female will marry an outside man into the reserve. The decision process is similar to the above in Figure 4.3: if (1) the female (wife) has no sibling, or (2) though she has siblings, all of them are females and she is the youngest among them, then her husband and she will remain in her original household with a probability of 0.58. Otherwise, they will initiate a new household. The parameter of 0.58 is based on our field observations and research results of An et al. (2003), where the researchers pointed out that most of the youngest child (especially son) prefer to live with parents after marriage for reasons such as taking care of their children and helping them with house chore. We set this parameter subject to change for two reasons: (1) there is some degree of uncertainty for its value, and (2) this parameter stands for the leaving-parental home intention and thus is subject to changes in perceived availability of land

and timber, or any other changes that cause local young adults to change their leaving parental home decisions. Under similar reasoning, the same value is used for this parameter in situations (2) and (3) later in this section.

(2) A local male brings an outside female into Wolong through marriage:

For a male in the single male group, if a random number generator creates a number smaller than the female_move_in rate of 0.043% (Section "Data collection, preparation, and integration"), then this male will marry a woman outside the reserve and bring her into the reserve (Figure 4.4). Then the decision regarding where to live after marriage is based on the following rule: unless he has siblings or a younger brother, his wife and he will remain in his original household with a probability of 0.58; otherwise they will initiate a new household.

(3) A local male marries a local female:

This situation is slightly more complex than the above two situations. Actually, most of the marriages are in this form. Based on our field observations and An et al. (2003), we developed the flow chart as shown in Figure 4.5. When two local singles get married, if the husband (1) has no siblings, or (2) has only female siblings (sisters), or (3) is the youngest among male siblings, then the couple live in the husband's original household with a probability of 0.58; otherwise check the sibling status of the wife. If she (1) has no siblings, or (2) she has only female siblings (sisters) and is the youngest among them, then the couple live in the wife's original household with a probability of 0.58. Otherwise, the couple initiates a new household.

- Childbirth

The event of childbirth only happens to females in the married group; and this group is explained earlier in this section. For easier explanation, suppose that the woman under consideration is called M (indicating mother). As mentioned in the introduction of the Person class, each person has a birth plan that is used to set the number of children he/she may have. As indicated in Liu et al. (1999a), the number of children for each couple is 2.5. We use a binomial random variable Y to assign the number of children that M would have (Figure 4.6). Since most families do not have more than 5 children (Wolong Administration 2000; also An's field observations), we assume she would have 0, 1, 2, 3, 4, and 5 children with the probabilities of 0.031, 0.156, 0.313, 0.313, 0.156, and 0.0313. The accumulative probabilities are 0.031, 0.188, 0.500, 0.813, 0.969, and 1, which are used to set probability intervals later. This is based on the famous statistical question of flipping a coin N (N=5 here) times and observing number of heads above (Y), where the probability of success (observing heads up) is 0.5, and Y is a random variable that could take values from 0, 1, …, to 5. From binomial distribution, the average of Y is $n \times p = 5 \times 0.5 = 2.5$ (number of children per mother). The probabilities are computed by the following equation:

Prob. (Y=y) = $\binom{N}{y} \times p^{y} \times (1-P)^{(N-y)}$, where $p$ is the probability of "success".

Therefore, if the random number generator generates a number (1) smaller than 0.03125, then M would have a plan of 0 child (she does not want a child); (2) between 0.03125 and 0.1875, then she would have one child; (3) between 0.1875 and 0.5, then she would have two children; (4) between 0.5 and 0.8125, then she would have three children; (5) between 0.8125 and 0.96875, then she would have four children; and (6) between 0.96875 and 1, then she would have five children. See above paragraph for how these numbers are obtained. On the other hand, we also set another option (called overloading in Object-oriented programming) for number of children to be set for each adult woman: simply randomly choose a number between two integer bounds with equal probability. For instance, to randomly choose between 0 and 4 (0 and 4 included) years, then 0, 1, 2, 3, and 4 (years) each have a probability of 1/5 to be chosen. This makes the average number of children to be 2, corresponding to a model test regarding this parameter.

For other parameters, we set their values based on our field observations. Birth interval (age difference between two consecutive children) is randomly chosen between 1 and 6 years because the averaged birth interval is around 3 years. The first kid interval (the time between marriage and birth of first child) is set to be 1, 2, or 3 years. All these values can be changed for different purposes such as sensitivity or uncertainty analysis and policy design and test.

Given these parameters, we simulate the childbirth in such a way: (1) for a female in the married group, check if she already has as many children as set up by her birth plan. If so, go to the next year and do nothing; otherwise, (2) check if she has reached her upper birth age, which is set to be 50 years old (could be changed by users) in this study. If she has, go to the next year and do nothing; otherwise, (3) check if she has child/children or not. If she does not have a child yet, (4) check if enough years (determined by first kid interval) have passed since her marriage. If not, go to the next year and do nothing. If so, she will give birth to a baby. (5) Starting from (3), if she already has child/children (but less than her birth plan), then (6) check her youngest child's age. If the age is equal to or greater than her expected birth interval, then she will give birth to a baby; otherwise, go to next year and do nothing.

- Household dynamics

In according with all the possible events for each individual, the household may decrease or increase in size, be initiated, or dissolve. When a new household is initiated, it is randomly assigned a site that is within a certain distance from its parental or original household. This distance, set at 800 m as default based on our field observations, is a parameter subject to change. Household dynamics is updated on a yearly basis.

**Landscape submodel**

- Path finding

Here the basic unit is pixel with resolution varying from 60 m to 360 m, depending on the needs of the simulation. When human demographic factors (population size, number of households) are the major concern, a coarser resolution (e.g., 360 m) is used to save computer memory and running time. When landscape characteristics (e.g., forest growth, areas of panda habitats) are of interests, a finer resolution (e.g., 60 m) is used to capture more details of the landscape.

Due to data limitations, we only consider forest growth using the simplified forest cover classification scheme presented in Section "Data collection, preparation, and integration". According to Yang and Li (1992), the growth model for class 1 (deciduous forests) is set to 0.6 $m^3$/ha/year if the vegetation age is younger than 20 years, 0.8 $m^3$/ha/year if the age is between 20 and 80 years, and 1.0 if the age is older than 80 years. For class 2, the rate is set to 2.0 $m^3$/ha/year regardless of the age. For class 3, the rate is set to 1.5. The maximal volumes for these three classes are set to be 350, 400, and 300 (the average of the first two numbers), we set the growth rate to zero when the volume of a pixel reaches its upper boundary.

Finding the path to collect fuelwood is a primary process in landscape simulation, and Figure 4.7 illustrates this process. In Figure 4.7 (a), the household on the lower right corner needs to determine where to cut a certain amount of fuelwood, which has been determined by a number of socioeconomic and demographic factors (An et al. 2001) and the probability of switching to electricity (An et al. 2002). Here a set of artificial intelligence rules are used, such as the rule of limited viewing scope, the rule of saving effort (decreasing preferences over a spectrum of down slope, flat plain, and up slope), and so on. As an illustration, a closer look at the decision process may help (Fig. 8 (b)). The fuelwood collector from the household has a limited scope, so (1) he/she only chooses among the pixels with forest within the dashed window of size 5×5 (the window size is a parameter to be set by the user, 5×5 is only used for demonstration). (2) Within this window, only four pixels have forests, and then the question is to ask which pixel has the least cost. Starting from the lower pixel (or any other one), the collector would not go astray too much (this consumes more energy, at least conceivably), so we assume that his/her path-finding behavior is confined by the two southeast-northwest lines parallel to an assumed line cutting across the household and the pixel, where the distance between these two lines is a parameter to be set. (3) Since he/she would not turn back while carrying a load of fuelwood, we assume that he/she goes northwest and does not go beyond the forest pixel, therefore, the two lines that are perpendicular to the above two southeast-northwest lines. Within the area set by these four lines, he/she chooses the least-cost path. (4) Starting from the forest pixel, he/she chooses the pixel with smallest elevation and goes northwest as indicated by the arrow. For simplification, at some point if the household pixel is within one pixel to his/her standing pixel, he/she goes to the household directly. (5) He/she keeps doing in this manner until the household pixel is reached.

Up to this point, the path should be determined. The Euclidean distance between two neighboring pixels with common sides equals the pixel size (or the resolution), and that between two diagonally connected pixels is pixel size times 1.414. Last, Euclidean distance is corrected by the slope between the two neighboring pixels. Adding all such corrected distances along the path leads to the cost distance between the household and the pixel. For all the remaining three forest pixels, the same routine is used to find the cost distance. Then at that specific year, the collector chooses the pixel with the least cost distance.

- Fuelwood site selection

For each household, we choose all the forest pixels within a certain buffer distance (3600 m as default based on unpublished field data from He et al. 2003; a parameter subject to change) and put them in a list. We then calculate the cost distance between each forest pixel and the household using the method as described above. We then group all these forest pixels into three categories for pixels that are 1080 m, between 1080 and 2160 m, and over 2160 m from the household. This classification is based on what He et al. (2003, unpublished field data) have found: 48.1%, 27.3%, and 24.6 % of the households collected fuelwood at sites that were 1080 m, between 1080 and 2160 m, and over 2160 m from their households in 1990s. Therefore, if the random number generator creates a number smaller than 0.481, between 0.481 and 0.754, and greater than 0.754, the household will collect fuelwood in sites corresponding to the above distances.

We also apply artificial intelligence to the household under consideration: once it selects a site to collect fuelwood at a given year, it would go to the same site next year as long as forest is still available. Doing this not only matches our field observations, but also saves memory and time in computing and running the program: once the starting site is determined, it can be saved as an attribute as the household. Next year, the household will select this site without going through all the processes as described above. Once this site is deforested to a certain level (less than 10 $m^3$), the household simply moves to its neighboring pixel.

- Habitat determination

Another important component is to determine habitat. According to Liu et al (1999a), any pixel with the elevation between 2250 and 3250 m, the slope less than 30 degrees, and with canopy forest is viewed as highly suitable or suitable habitat. We combine "highly suitable" and "suitable habitats" into one category "habitats" and exclude "marginally suitable habitats" from habitats in our simulation because we want to give a conservative estimate of panda habitats. In programming, since the elevation and slope for a specific pixel are not subject to change, the only possible change is the amount of forest. If the amount of forest is cut to 10 $m^3$/ha or less[10] in a certain year, then this pixel will be changed to non-habitat. The rationale for not using zero $m^3$/ha as the threshold for non-habitat is as follows: when the majority of the forest on a pixel is removed, it will lose its uses for pandas as their cover and shelter. In addition, the understory bamboo in a site with sparse (less than 10 $m^3$/ha) or no canopy is not preferred by pandas (Schaller et al. 1985).

**Socioeconomic submodel**

- Potential fuelwood demand

Fuelwood consumption is calculated on a household basis in IMSHED. According to An et al. (2001), the fuelwood demand for a household consists of three components: (1) fuelwood for cooking, which equals 0.467×household_size + 0.703, (2) fuelwood for heating, which equals 7.23 + 1.37×senior_index—0 for households without senior(s) and 1 for households with senior(s), and (3) fuelwood for cooking pig fodders, which equals 24.856×corn_land_area – 0.338. Component (1) is a function of household size—since our model updates the size of each household on a yearly basis, this component is also calculated annually. Component (2) depends on our annual check of whether a household has a person over 60 years old: if there is, senior index is set to 1, otherwise 0. Component (3) depends on the area of the corn land, which was called

[10] The value 10 is a parameter that can be changed in the model. Doing so gives a more conservative estimate of the area of panda habitat.

corn/potato land because these two crops are usually grown together and both are primarily used as fodders. The original corn land data for each household are read into the program through a text file that contains all the household attributes (Section "Major agents"). As time passes, if a person initiates a new household from her/his parents', he/she gets a portion of land proportional to the two household sizes. For instance, a household has 0.3 ha cropland before formation of the new household. After this formation, suppose the parental household has 4 people, and the new household has 2, then the new household can get a portion of 2/(2+4), or one third of the cropland (0.1 ha).

In all the other situations such as a childbirth and out-migration of a former member, we keep the cropland unchanged because China lacks a system of redistributing land based on household size in a timely manner, although some farmers complain about this.

- Electricity demand

The above fuelwood demand does not consider the switch probability to switch from fuelwood to electricity, and is thus incomplete. This switch probability is determined by the age, gender, and education of the household head, household annual income (household annual expense as a proxy, see An et al. 2002), current electricity price, outage frequency level, voltage levels, distance of fuelwood transportation, and location of the household under consideration (1 for Wolong Township and 0 for Gengda Township; An et al. 2002). The above attributes are set as instance variables of the Household class (See Section

“Major agents”). The data for household income are incomplete (220 households were interviewed in 1999), so we use the median income of 6854 Yuan (the Chinese currency unit, 1 US \$ = 8.3 Yuan in 1999) for each household. The distance of fuelwood transportation, computed in Section “Landscape”, is dynamic over time because the available forests for fuelwood will be located farther and farther away from households given that the current population trend continues.

To be consistent with the model of electricity demand in An et al. (2002) and allow for policy test, hypothetical prices, outage levels, and voltage levels are set as instance variables and built into IMSHED model. For general model running, we set them to their current levels. If the modeler wants to test how changes in these factors impact panda habitats, they can be changed to levels corresponding to any potential policy regime.

- Fuelwood demand

When an electricity substitution program is considered either with higher quality or lower price, the ultimate fuelwood demand is computed as the fuelwood demand derived above multiplies the probability that the household does not switch to electricity, which is 1 minus the probability of switching from fuelwood to electricity as computed above.

**Programming for simulation**

The model is programmed using Java-Swarm 2.1, a collection of software libraries developed by Swarm Development Group (http://www.swarm.org) for multi-agent simulation programming. As an object-oriented and highly hierarchical tool kit, Swarm (Java version; it also supports Objective-C) provides many readily useable packages (classes, interfaces) for Java programmers. Swarm allows for a hierarchical structure for agent organization and management, which means a higher-level agent in the hierarchy can include and manipulate a number of lower-level agents and their actions. In addition, by resorting to a few readily made application programming interfaces (API's), IMSHED has a user-friendly and graphical interface (Figure 4.8) to set and probe parameters and run the program.

When the user starts the program, a control panel with "ProcCtrl" (stands for process control) as the title, a parameter manager with "ModelSwarm" as the title, and a display manager with "ObserverSwarm" as the title come out, as shown in Figure 4.8 (a), (b), and (c), respectively. The control panel allows the user to start, stop, and quit the program at any time by clicking the 'Start", "Stop", and "Quit" buttons. If he/she wants to run the program at each time step (year for IMSHED), he/she can click the "Next" button—then the program will run for one time step until the next click. The "Save" button lets the user save the simulation results during the simulation.

The parameter manager lets the user change some of the parameters for simulation. For example, entering 0.0384 in the space for "collegeRate" and then clicking "Start" in the control panel will run the model with a user-adjusted doubled college attendance rate (the observed value is 0.0192). This avoids going to the code and making changes, which is more error-prone and inconvenient, especially for people other than the programmer. If the user wants to identify the names and settings of all parameters, he/she can right click the button with the circle and cross at the upper-right corner to display a window with more details (Figure 4.8 (d)). If the user wants to display the graphics at a different display frequency (e.g, 2 years), he/she can change the number of "display Frequency" to 2 in Figure 4.8 (c) and the model output will be displayed every other year.

**Model testing**

Due to lack of accurate data for current forest volume (Section "Major agents"), we test the model only by (1) comparing the predicted and observed population sizes over 1996-2000, and (2) comparing the predicted and observed numbers of households over 1996-2000.

We also conduct uncertainty or sensitivity analyses, and the choice depends on the magnitude of the possible change on the associated variables. We calculate the changes in panda habitat areas in response to a 10% or 20% change in a number of pre-selected factors, including the leaving parental home index ranging from 0 to 1, the average number of children for each woman, and the college rates (See Section "Demographic sub-model" for their definitions). We also decrease the electricity price by 0.05 Yuan, increase voltage levels by one level (0 for low, 1 for medium, and 2 for high; if the original voltage is 2, then remain at 2 without increase), and decrease outage levels (0 for low, 1 for medium, and 2 for high; if the original voltage is 0, then remain at 0 without decrease). The number of runs is 5-10 (with simulation length to be 20 years), depending on the variability of the simulation results. To measure the sensitivity, we employ the following sensitivity index (Jørgensen 1986):

$$S_x = (dX/X)/(dP/P)$$

Where $P$ is the value of independent variable, $dP$ is the value for a small change of $P$, $X$ is the value of dependent variable, and $dX$ is the corresponding change in $X$ in response to the change in $P$. We also conduct two-sample t-test between baseline simulation results and the simulation results under the changes in above variables. The purpose of doing this is to make sure whether the changes in the dependent variables are statistically significant or simply due to the stochastic processes in the model as mentioned earlier in Section "Demographic sub-model".

**Scenario analysis**

Here we are interested in finding how population size, number of households, and panda habitats respond under varying conditions: (1) Status quo scenario: using the current conditions; (2) desirable scenario: setting the sensitive factors and a few demographic factors to values that would benefit panda habitat conservation. (3) Undesirable scenario: setting the factors to values that would degrade panda habitat. For details of these scenarios, see Table 4.1. The use of these very divergent scenarios may provide some insight into the range of possible trajectories of panda habitat conversion, and its consequent effect on the likelihood of giant panda survival.

## Results

### Model testing

Based on data availability, we start our simulation from 1996 and compare the predicted and observed number of households from 1997 to 2000. Our data source for observations is from M. Liu (2000). We can see that the model predicts the population size and number of households well, especially the latter (Figures 4.10 and 4.11). Our predicted annual population increase rate is 0.72% (a total of 14.41% over 20 years, Table 4.3), while the population growth rate mentioned in Liu et al. (1999a) is 1.05% (a total of 14.65% increase over 14 years). This slight decrease in population increase rate can be seen from the levering-off trend of population size since 1990 (Figure 4.11). Our predicted annual increase rate for the number of households is 1.11% (a total of 22.20% over 20 years, Table 4.3), higher than the increase rate of population size, i.e., 0.72%. This result is consistent with the pattern from 1975 and 1999 (Figure 4.11) where number of households increased at a higher speed than did population size, though the magnitudes of both rates (120% for number of households and

70% for population size) are much higher than what we predicted. This slower increase trend can be seen since 1990 for population and 1995 for number of households (Figure 4.11).

The uncertainty or sensitivity analyses show that all the electricity-related factors significantly change panda habitats over 20 years when compared to the baseline simulation, which is defined as the simulation for 20 years under the status quo conditions. For instance, a 0.05Yuan electricity subsidy can save about 17.86 $km^2$ panda habitat, which corresponds to approximately 2.95% reduction (from 4.74% to 1.79%; Table 4.2). Similarly, an increase in voltage and decrease in outage levels have significant effects on panda habitats.

While demographic factors appear to have a significant impact on human population and number of households over the next two decades, their impacts on panda habitats are not as apparent as the socioeconomic factors reported in the previous paragraph (Table 4.3). The habitat area at the end of the baseline simulation over 20 years is 578.43 $km^2$, approximately 4.74% decrease under status quo situations compared to 1996.. An increase in leaving parental home intention significantly increases number of households (142 more) and decrease panda habitat (2.93 $km^2$) in relation to the baseline simulation, though the magnitude of the latter is not large compared to the habitat area in the baseline simulation (578.43 $km^2$). Increasing college rates does not significantly affect panda habitat, but moderately affect human population size (significant at 95%, though sensitivity value is only –0.03), and number of households (significant at 95% level but small sensitivity value). The sensitivity indices in Table 4.4 are small (some even close to zero), indicating that the relative changes of the dependent variables in response to those independent variables are small. This fact will be further discussed in Section "Conclusions and discussions".

**Scenario analyses**

- Number of households and population size

Figures 4.13 and 4.14 show the trend of population size and number of households under these three scenarios. The number of households in 2016 could range from approximately 925 households to 1563 households, and population could range from 3657 to 6332. Correspondingly, the increase rates for number of households are 3.70% and 75.22% over 20 years under these two extreme conditions. The increase rates for population are -9.78% and 56.23%. These demonstrate that human population and number of households are highly subject to policy factors.

- Habitat dynamics

Panda habitats would experience different levels of degradation based on our simulation. Figure 4.14 shows that the total area panda habitats change from around 603 (desirable scenario) to 567 (undesirable scenario) $km^2$, a difference of 36 $km^2$ that constitutes about 5.9% of the area of panda habitats in 1996. Figures 4.15-4.17 show the trajectories of habitat spatial change under these two scenarios. Figure 4.17 shows that the habitat decrease mainly focuses on areas around households, indicating that people cut the nearest forests first, they gradually move outwards for available forests, which is consistent with what He et al. has found (He 2003, unpublished data).

## Conclusions and discussions

### Model results and policy implications

Because the remaining panda habitat is already small, a decrease of 4.74% (about 29 $km^2$) under the status quo situation (the status quo scenario) over 20 years would be more devastating to panda conservation. Furthermore, the distribution of panda habitats should be of concern. Pandas usually prefer those areas that humans also tend to visit for fuelwood collection. So this decrease in habitats may occur in panda's preferable habitats. Thus total area of panda habitat alone does not represent potential habitat fragmentation. Another important issue regarding panda habitats is that we have not considered the home range of a typical giant panda. According to Schaller et al. (1985), a panda usually lives within an area of 2 $km^2$. In our model, areas smaller than 2 $km^2$ are also counted as panda habitats, so we may overestimate panda habitats. However, this estimate could be viewed from another perspective: within all the potential panda habitats (green blocks in Figure 4.16 (a) and (b)), there might be pandas; within all the areas that are counted as non-habitats, there should be no pandas. Therefore, the total area of panda habitats under status quo scenario is most likely an upper boundary for panda habitats, and the ratio of 4.4% should be viewed as a conservative estimate of panda habitat loss.

Due to the lack of accurate forest volume data for dominant species in different pixels, difficulties arise when computing accurate areas of panda habitats in a given year. As we are primarily interested in what socioeconomic, demographic, and ecological factors would lead to panda habitat changes, we still compute these areas and use them in a relative sense. For instance, 3 pixels of 90×90 m with 50, 40, and 30 $m^3$ of pine canopy with increasing cost-distance to a household (scenario 1) might respond to a fuelwood demand of 80 $m^3$ in this way: pixel 1 is deforested first, then some of pixel 2, and pixel 3 will remain with total volume of 30 $m^3$. However, three pixels with 30, 40, and 50 $m^3$ (scenario 2) might respond in this way: pixel 1 will be deforested first, then all of pixel 2, and part of pixel 3. Scenario 1 will result in two pixels (2 and 3) with forests (potential habitats if other conditions are also satisfied), while scenario 2 will result in only pixel 3 with forests at the end of year 1. In terms of total volume deforested at year 1, these two scenarios are the same (80 $m^3$). In terms of total area of panda habitats that are left, these two scenarios are different at year 1: scenario 1 will count two pixels (pixels #2 and #3 totaling 90×90×2=16200 $m^3$) as habitat, while scenario 2 will count one pixel (pixel #3 totaling 90×90=8100 $m^3$) as habitat. However, if the time is long enough, this type of effects will be minimized when considering more pixels rather than 3 as above. For the same example above, if the fourth pixel has 40 $m^3$, then all the four pixels will be deforested in both scenarios by the end of year 2 because they each have 160 $m^3$ forest volume. In this case, we observe the same total deforested area and panda habitat area at year 2. As time goes on and more pixels are considered, new discrepancies between these two areas will likely occur, but will certainly fluctuate around a certain value. Thus we conclude that given a certain number of pixels and total amount of forest volume fixed, the varying distribution of the volumes among the pixels would not affect greatly the habitat area if the simulation time is long enough.

Though the sensitivity indices are small in response to small changes in the demographic variables (Table 4.4), the cumulated effects over longer time should be more obvious. For instance, when a couple decides to live with their parents at year 16, they will use less fuelwood than what they would use if living independently. By year 20, the total amount of fuelwood thus saved would not make big difference. But in the long run (e.g., 30 years), the cumulated amount of fuelwood they have saved should be much bigger than that at year 20. Above results under desirable and undesirable scenarios show that human socioeconomic and demographic factors are important in affecting panda habitats. With increasing human population and number of households, the panda habitats will continue to be lost over time. However, when policies that encourage migration or the use of electricity are implemented, panda habitats will be saved to varying degrees. For instance, an electricity subsidy of 0.05 Yuan could reduce the habitat loss from around 29 $km^2$ to 11 $km^2$. If combined with other conservation activities, more habitats could be saved. However, the demographic factors does not affect panda habitats significantly, probably due to the fact that the simulation length (20 years) is not long enough to show their impacts. Longer simulation would be necessary in the future.

In the future, effort should be directed to validating the model by household locations. It is preferable to collect more detailed forest volume data and further validate the model, which would make the model more reliable and powerful in studying spatio-temporal dynamics of panda habitats, and facilitate the application of the model in balancing the needs for panda conservation and those for human well being. In addition, the integration of ABM and GIS in this study is still fledgling, not allowing extensive spatial analysis. This difficulty is partly due to the fact that many readily usable functionalities in GIS (such as finding the cost distance) have to be coded in Java Swarm by the authors, which sometimes become a heavy burden. We expect to use ESRI's MapObjects software for more spatial display, query, and analysis.

**Methodology: ABM and GIS**

Regarding the methodology of building the model for interdisciplinary integration, this model has built upon the fuelwood demand model (An et al. 2001) and the econometric model for electricity demand (An et al 2002) while computing the fuelwood demand on household basis. The research methods and results about young adults' leaving parental home and forming their own households have been partly integrated in this model. For example, while setting up the rules for new household formation (Section "Demographic sub-model"), we use an index of leaving parental home to represent the likelihood of leaving parental home when the person under consideration has to make the decision.

Aside from practical purposes such as developing a model for making policy to conserve local pandas, this model is also oriented towards building and testing the integrated approach that uses agent-based modeling in combination with GIS. From the above analyses, we believe that this approach is useful in integrating individualistic and transdisciplinary data into the model, which has been viewed very significant in studying environmental sustainability (Clark 2002). This bottom-up approach "starts from the 'parts' (i.e., individuals) of a system and then tries to understand how the system's properties emerge from the interactions among these parts" (Grimm 1999). As a result, this approach can efficiently deal with many research needs that traditional approaches cannot (or are difficult to) deal with, usually with higher accuracy for predictions. However, this increased accuracy can only be found at the aggregation level such as human population size or number of households because some stochastic processes are used at the agent level, such as individual person's leaving parental home decisions.

Developing and using ABM does not discredit the traditional state variable, statistic, or analytic approaches. On the contrary, in many situations ABM uses these approaches as complements because it is unnecessary (sometimes impossible) to count every detail of the agents under consideration. For instance, when computing the fuelwood demand for cooking pig fodders, we use a regression model to accomplish this ("Fuelwood demand" in Section

"Demographic sub-model"), and the regression model is an average trend derived from a number of households. It is both a science and an art to balance between using individualistic or averaged trend data and find an appropriate level of resolution and aggregation. All that can be said safely here is that the choice depends on our research needs, how many additional insights individual data can bring in, and whether the time, budget, and other conditions (say, computer speed and memory) can afford.

The methodology in this research has great potential to study human-environment interactions with higher power of prediction and explanation by including more individual-level data and more inter-individual relationships. In this study, we integrate geographical, ecological, socioeconomic, and demographic data into different levels or types of agents (persons, households, pixels), and predict the spatial patterns of panda habitats over varying temporal and spatial scales. Another strength of this methodology is its power to study how changes in demographic factors, in addition to changes in socioeconomic factors, could impact the panda habitats (or other environmental indicators elsewhere) over time in a spatially explicit manner. In summary, as a tool to explain or predict overall landscape patterns as a result of actions of many agents, this methodology is powerful in integrating interdisciplinary data across varying scales, and thus could be applicable to many human-environment studies in other parts of the world.

**Figure legends (Some of the figures are color images)**

Figure 4.1. (a) An object in object-oriented programming with data and operations (methods) combined. (b) Interface and implementation of object-oriented programming.

Figure 4.2. Conceptual framework of IMSHED.

Figure 4.3. Individual-based demographic simulation.

Figure 4.4. Processes determining whether an new household is initiated or not when a local single male brings a outside female into Wolong through marriage.

Figure 4.5. Processes determining whether a new household is initiated or not when two local single persons get married.

Figure 4.6. Processes determining whether and when to give birth to a child

Figure 4.7. The procedures to find the least-cost path to collect fuelwood.

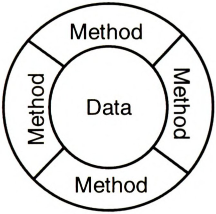
Figure 4.8. Model interfaces in IMSHED.

Figure 4.9. Predicted and observed number of households between 1997 and 2000.

Figure 4.10. Predicted and observed population sizes between 1997 and 2000.

Figure 4.11. Population and number of households between 1975 and 1999.

Figure 4.12. Predicted population human sizes over 20 years under (a) current situation, (b) undesirable situation, and (c) desirable situation. The starting simulation time 0 is 1996.



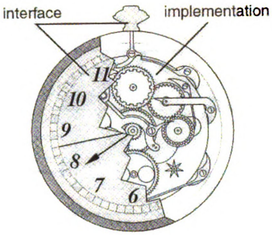




Figure 4.1. (a) An object in object-oriented programming with data and operations (methods) combined. (b) Interface and implementation of object-oriented programming.

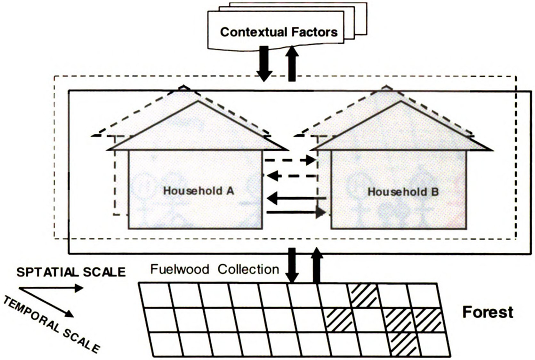



Figure 4.2. Conceptual framework of IMSHED.

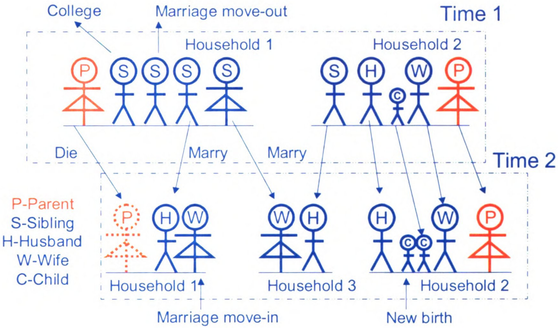



Figure 4.3. Individual-based demographic simulation.

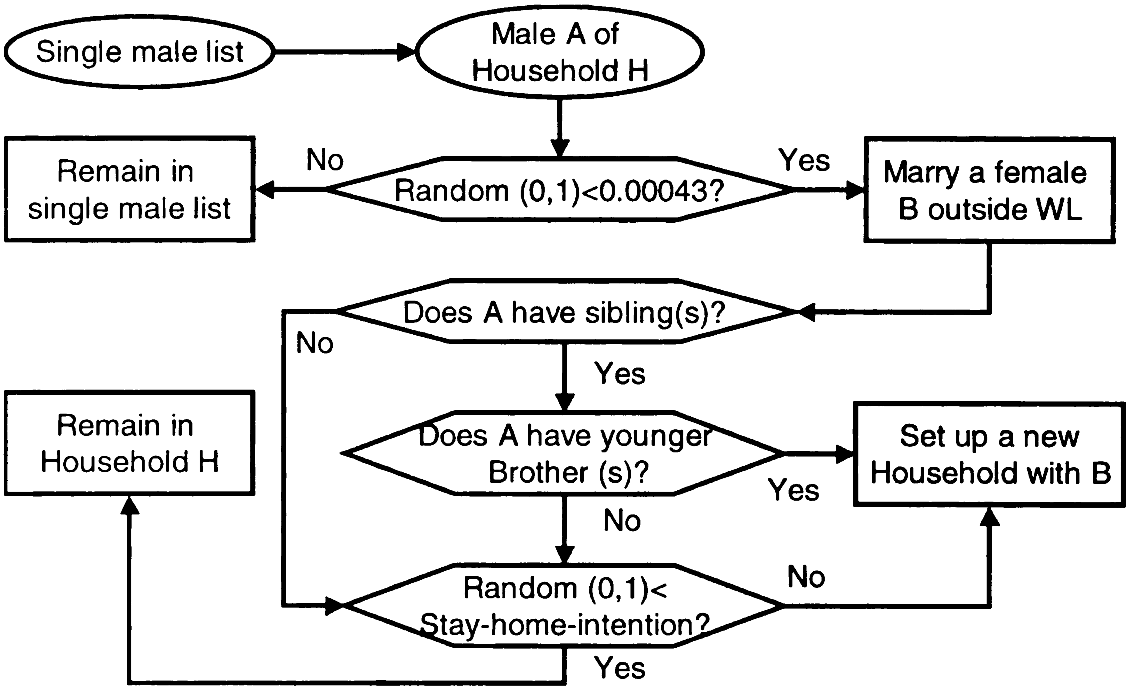



Figure 4.4. Processes determining whether a new household is initiated or not when a local single male brings a outside female into Wolong through marriage.

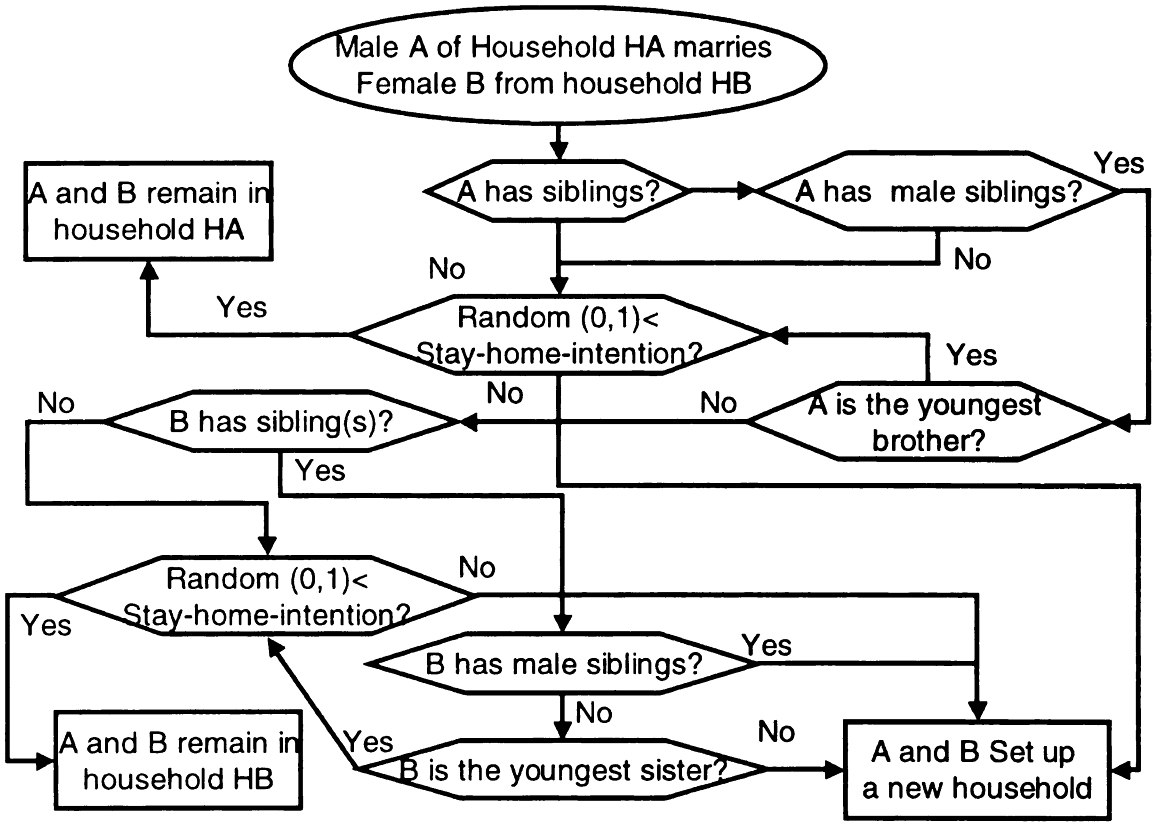



Figure 4.5. Processes determining whether a new household is initiated or not when two local single persons get married.

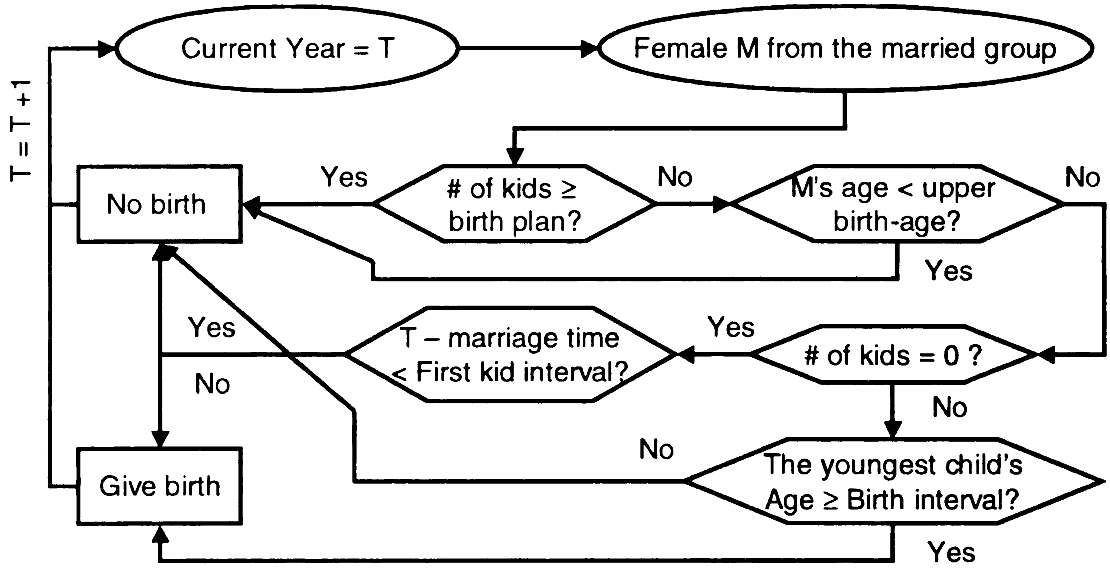



Figure 4.6. Processes determining whether and when to give birth to a child

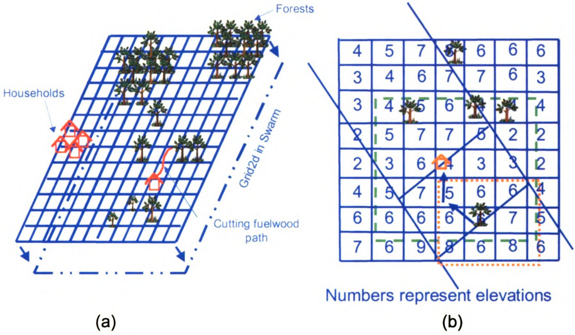



Figure 4.7. The procedures to find the least-cost path to collect fuelwood.

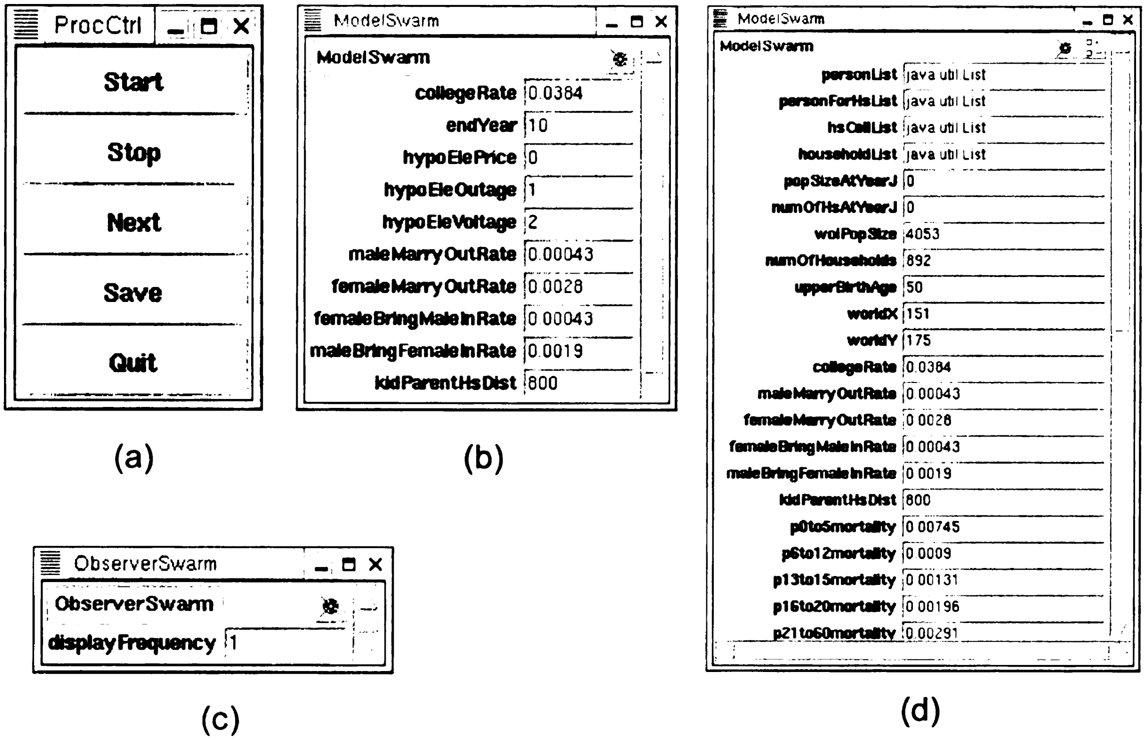



Figure 4.8. Model interfaces in IMSHED.

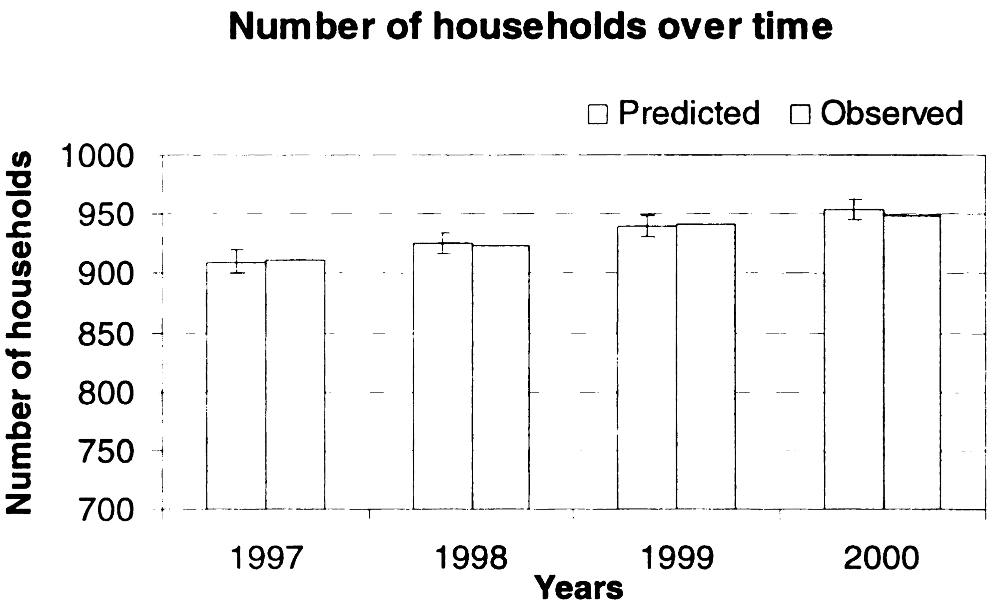



Figure 4.9. Predicted and observed number of households between 1997 and 2000.

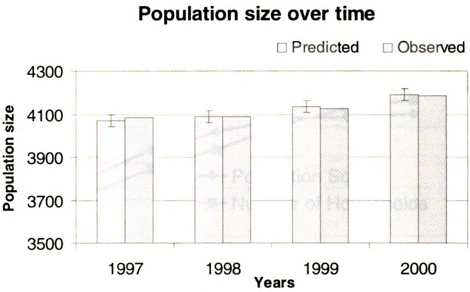



Figure 4.10. Predicted and observed population sizes between 1997 and 2000.

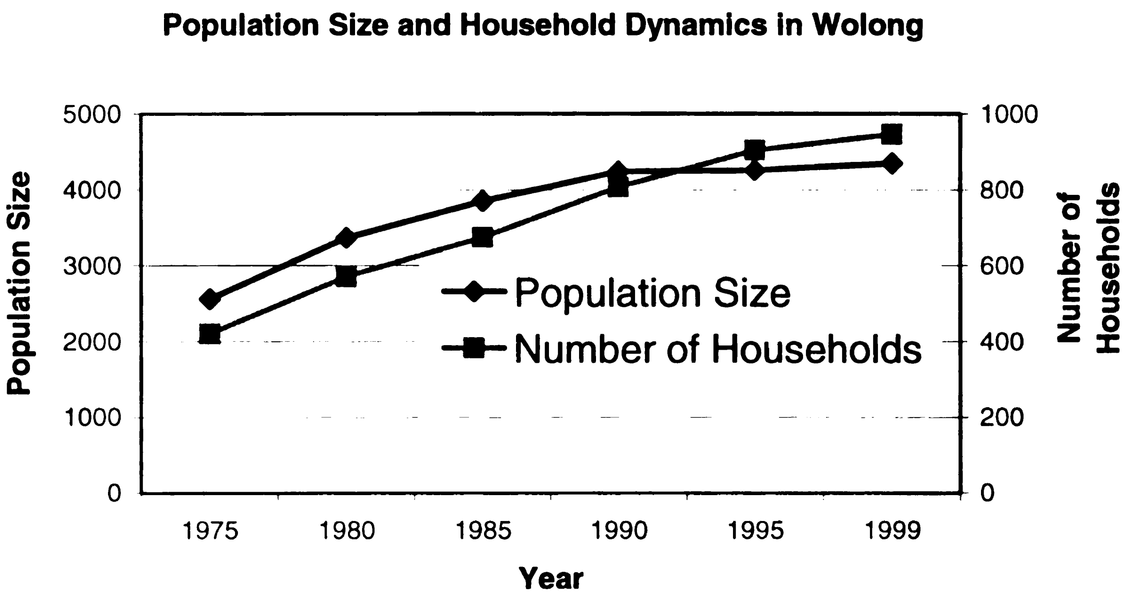



Figure 4.11. Population and number of households between 1975 and 1999.

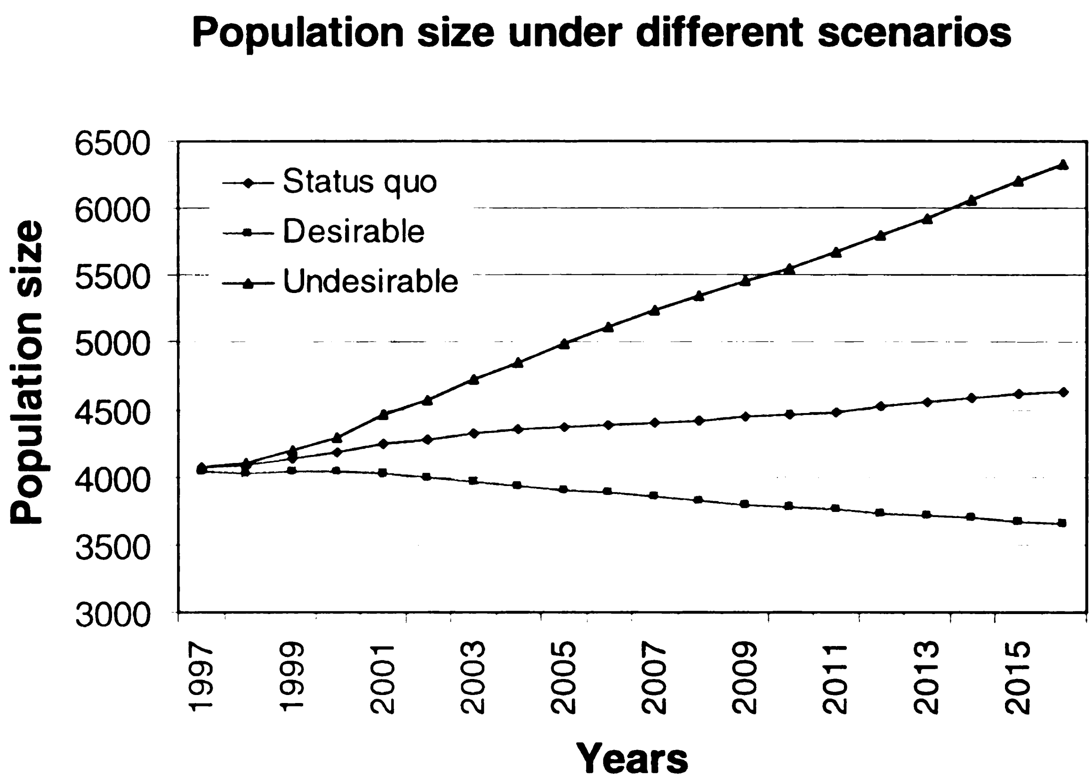



Figure 4.12. Predicted population human sizes over 20 years under (a) current situation, (b) undesirable situation, and (c) desirable situation. The starting time 0 is 1996.

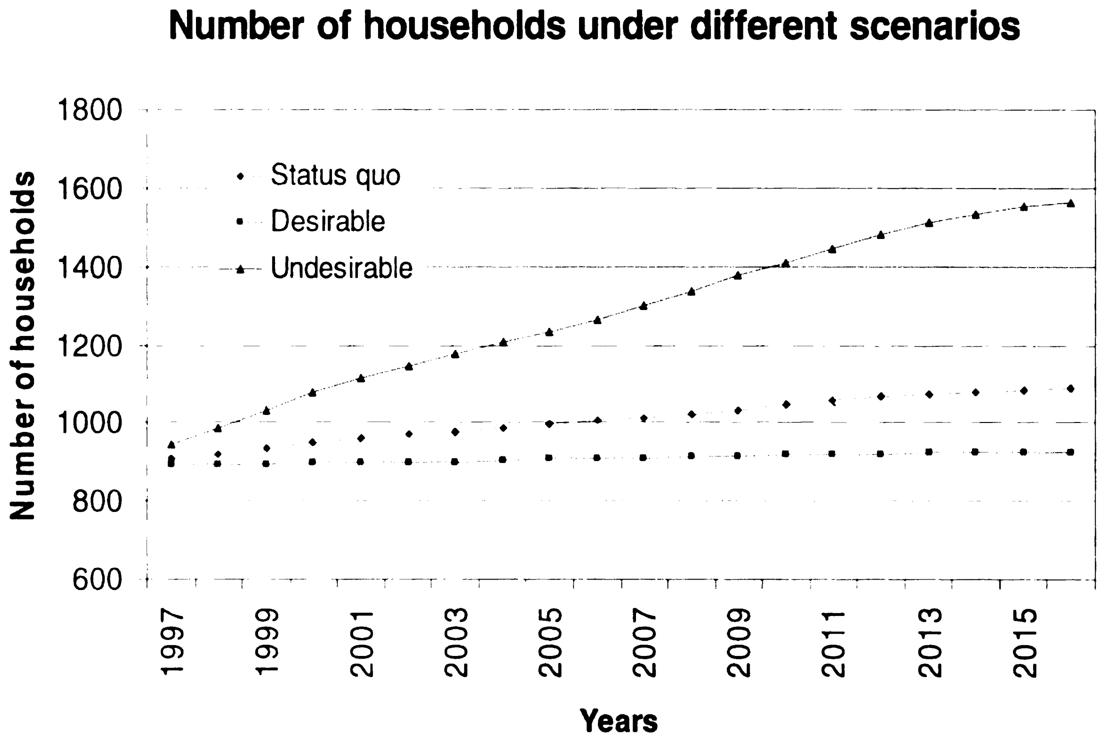



Figure 4.13. Predicted numbers of households over 20 years under (a) current situation, (b) undesirable situation, and (c) desirable situation. The starting time 0 is 1996.

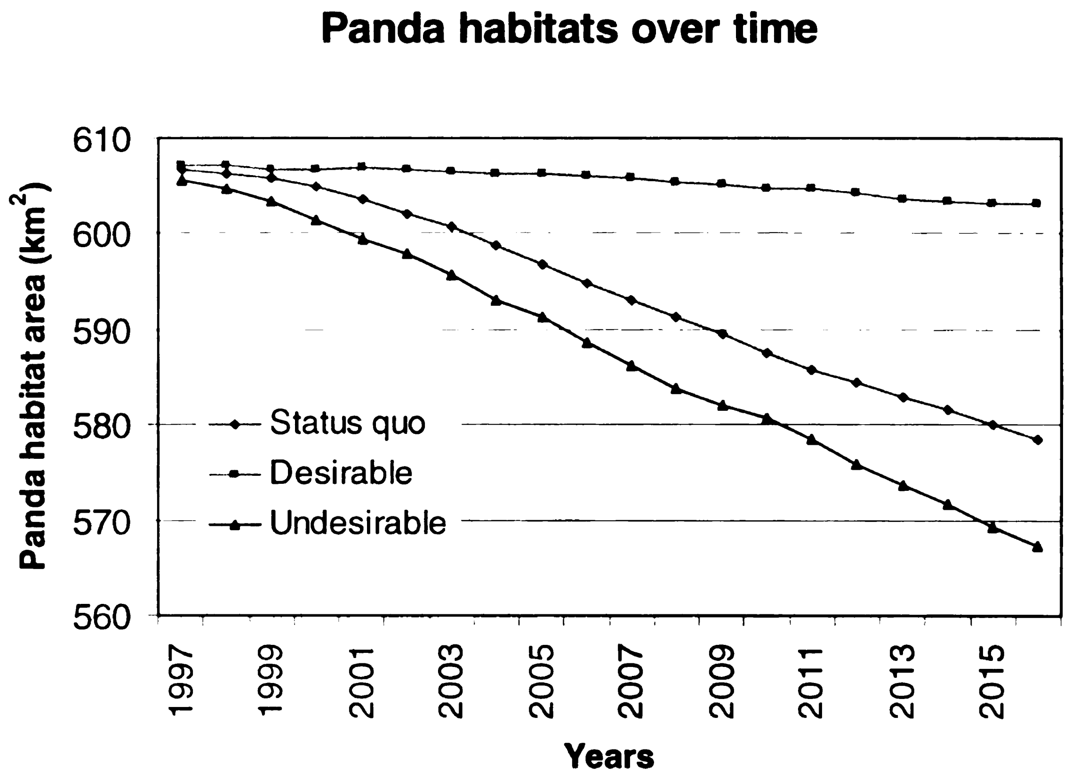
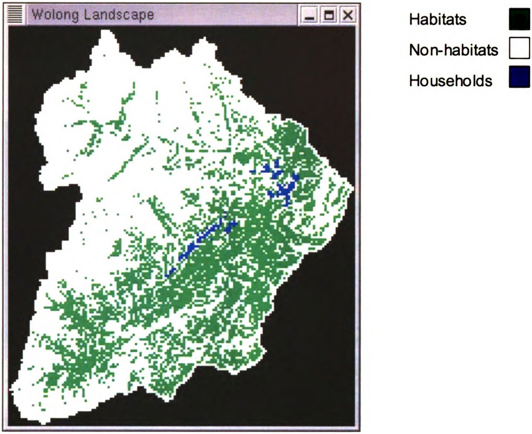
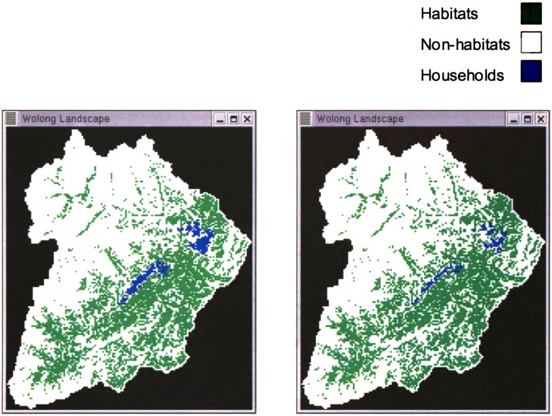



Figure 4.14. Predicted area of panda habitats over 20 years under (a) current situation, (b) undesirable situation, and (c) desirable situation. The starting time 0 is 1996.



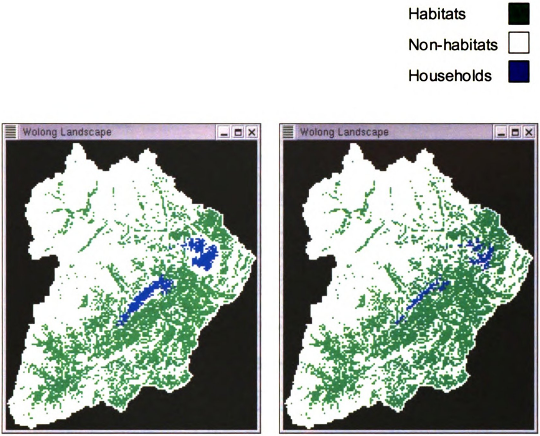

Current situation (year 1996)

Figure 4.15. Panda habitat spatial fragmentation and household distribution in 1996 (starting point).




(a) Undesirable scenario (2006) (b) Desirable scenario (2006)

Figure 4.16. Predicted panda habitat spatial fragmentation at year 2006 under (a) undesirable situation, and (b) desirable situation.




(a) Undesirable scenario (2016) (b) Desirable scenario (2016)

Figure 4.17. Predicted panda habitat spatial fragmentation at year 1016 under (a) undesirable situation, and (b) desirable situation.

Table 4.1. Definition of desirable and undesirable scenarios. The first numbers in the spaces below are the default values in the model, and the second values are those used in the associated scenarios.

| | Contents | Desirable scenario | Undesirable Scenario |
|---|---|---|---|
| Electricity | Price | 0.05 Yuan decline | Program canceled |
| | Outage levels | One level decrease | |
| | Voltage levels | One level increase | |
| Migration rates | Leaving parental home intention | 0.42 → 0.21 | 0.42 → 0.95 |
| | College rate | 1.92% → 30% (16-20 youth) | 1.92% → 0.0% |
| | Female marry-out rate | 0.28% → 20% | 0.28% → 0.0% |
| Family planning | Fertility | 2.0 → 1.5 | 2.0 →5 |
| | Birth interval | 3.5 → 5.5 | 3.5 → 1.5 |
| | Marriage age | 22 → 28 | 22 |

Table 4.2 Model testing results for electricity factors over 20 years. The numbers in parentheses are standard errors, while the double asterisks indicate significant (at 95% level) increase or decrease in relation to the baseline simulation data. The negative numbers are decrease rates compared with the starting situation in 1996.

| | Simulations | Panda habitats ($km^2$) | Change rate (%) compared to 1996 |
|---|---|---|---|
| Year 1996 | | 607.18 | -- |
| Year 2016 | Baseline | 578.43 (0.68) | -4.74 |
| | Electricity price 0.05 subsidy | 596.29** (0.59) | -1.79 |
| | Electricity outage decrease | 592.71** (0.78) | -2.38 |
| | Electricity voltage increase | 588.853** (0. 89) | -3.02 |

Table 4.3 Model testing results for demographic factors over 20 years. The percentages in parentheses are increase rates (decrease rate if negative) compared with the starting situation in 1996, while double asterisks indicate significant increase or decrease at 95% level in relation to the baseline simulation data. Single asterisk indicates a significant change at 90% level. College rate is the ratio between the number of people who go to college and the total number of people between 16-22 years old in a given year.

| Year | Simulations | Population size | Number of households | Panda habitats (km$^2$) |
|---|---|---|---|---|
| 1996 | | 4053 | 892 | 607.18 |
| 2016 | Baseline simulation | 4637 (14.41%) | 1090 (22.20%) | 578.43 (-4.74%) |
| | Leaving parental home intention (50% increase) | 4637 (14.41%) | 1232** (38.12%) | 575.50** (-5.22%) |
| | College rate Increase by 200% (1.92% to 5.76%) | 4325** (6.71%) | 1036** (16.14%) | 578.97 (-4.65%) |

Table 4.4 Model sensitivity test results for demographic factors over 20 years. College rate is defined the same as that in Table 4.3.

| Year | Simulations | Population size | Number of households | Panda habitats ($km^2$) |
|---|---|---|---|---|
| 2016 | Leaving parental home intention (50% increase) | -0.00 | 0.26 | -0.01 |
| | College rate Increase by 200% (1.92% to 5.76%) | -0.03 | -0.02 | -0.00 |

# CHAPTER 5

# IMPACTS OF DEMOGRAPHIC AND SOCIOECONOMIC FACTORS ON SPATIO-TEMPORAL DYNAMICS OF PANDA HABITATS

Special gratitude to:

Guangming He, Zai Liang, and Jianguo Liu

**Abstract**

In the Wolong Nature Reserve (China) for giant panda conservation, local households live a rural lifestyle that has caused forest degradation by cutting fuelwood. Based on field data and an Integrative Model for Simulating Household and Ecosystem Dynamics (IMSHED), we simulated the spatio-temporal dynamics of households and their impacts on panda habitat by keeping track of each family member's life history (including their individual needs, attitudes, and activities) and the dynamics of household agents when they interact with each other and with the environment through their activities over 20 years. Our simulations show that among all the demographic and socioeconomic factors under consideration, fertility, emigration, and providing cheaper electricity, and changing the age structure could change habitat quantity greatly.

## Introduction

Human activities have radically altered the earth's surface, oceans, and atmosphere, especially over the past 200 years (Turner et al. 1990), which reminds current generation of the warning by Malthus that unrestrained population growth would eventually be limited by natural resources (Malthus 1798). Though the last decade has seen a wide acceptance of making transition towards sustainable development (United States National Research Council 1999), the earth's life support systems have been greatly degraded due to an exceedingly rapid loss of biodiversity. Paralleling the growth in scientific research into biodiversity and the increasing recognition of biodiversity's esthetic quality, huge economic benefits, and vital ecosystems services (e.g., Ehrlich and Wilson 1991), research efforts have been called to study how multiple environmental stresses, social institutions and ecological conditions interact in various places (Clark 2002). In particular, changes in human demographic and socioeconomic factors (e.g., public policy) have been viewed to exert great impacts on the environment and need to receive more attention (e.g, Pebley 1998, Liu 1999a, Liu 2001, Lambin 2003, An et al. 2003b). Pebley (1998) suggested that environmental issues (such as effects of demographic variables on environmental outcomes) become one of the mainstream topics in demography rather than peripheral topics as in the past.

An increasing number of researchers, including ecologists, geographers, sociologists, and demographers, have conducted case studies to study human-environment interactions. For instance, Liu et al. (1999a) have investigated the potential impacts of demographic changes (such as age structure) on local biodiversity conservation, and found a higher proportion of labor force would further degrade the environment. To investigate how micro-level demographic factors affect land use and land cover changes in Amazon, Perz (2001) used multivariate models to link demographic factors to environmental outcomes at the household level. He found that farmers background (e.g., region of birth, initial wealth), neighborhood (e.g., distance to town) and institutional (e.g., titling status) contexts, off-farm income, and a household's demographic features (e.g., age of the household head, number of adults) exert great impacts on farm outcomes, including annuals, perennials, and pasture products. In dealing with changes in social organization of environmental consumption, Axinn and Barber (2003) has proposed that "households with access to nonfamily organizations in or near their communities are... more likely to consume environmental resources indirectly rather than directly", while those with few or none such organizations tend to reply on the natural resources themselves more directly, such as in a subsistence setting. However, studies of the impacts of these factors on the environment and the reasons that lead to these changes at individual or household level are rare, especially in a spatially explicit manner.

Complexities of many social or individual choices in such coupled society-biodiversity systems have often been hurdles to conduct such studies (United States National Research Council 1999). Such systems usually have variant socioeconomic, demographic, and/or biodiversity factors, coupled with many nonlinear relationships and heterogeneous spatial structures. Theories and methods of complex systems have been proposed to deal with these types of complexities, where the individualistic demographic and socioeconomic properties of the study targets can be captured and represented in modeling the choices and decisions of each resource consumer. Bottom-up approaches such as agent-based modeling (usually in relation to artificial intelligence) can play a crucially important role in this type of human-environment studies. It would be ideal if individual-level or household-level demographic or socioeconomic information could be included in such approaches and study how the environment would respond to changes in these factors.

**Study site**

An excellent site to study these issues is the Wolong Nature Reserve (Figure 1.1). Designated in 1963 with an area of 200 $km^2$ and expanded to approximately 2,000 $km^2$ in 1975, Wolong Nature Reserve has a human settlement comprised primarily (75%) of Tibetan residents. The giant panda (*Ailuropoda melanoleuca*), considered a national treasure of China and of concern to people around the world, has declined substantially in the reserve due to serious habitat degradation resulting from deforestation as the inhabitants cut wood for cooking and heating their households (Liu et al. 2001). The past two decades has witnessed a continual increase in annual fuelwood consumption (from 4,000 $m^3$ to 10,000 $m^3$), resulting in a reduction of more than 20,000 ha of panda habitat (Liu et al. 1999a). Subsequently, the panda population in Wolong

is estimated to have declined from 145 animals in 1974 (Schaller 1985) to 72 in 1986 (China's Ministry of Forestry and World Wildlife Fund 1989).

Paralleling the increased consumption of fuelwood, the number of households has been increasing at an even higher rate (124%) than the human population (69%). Specifically, there were 4,320 local residents and 942 households in 1998 (An et al 2001), compared to only 2,560 people and 421 households in 1975 (Liu et al 2001). The high population increase can be explained by the fact that the famous "one child" policy does not apply to minority ethnic groups such as Tibetans (Liu et al. 2001). The even higher rate of increase in household number, however, is due to an increasing preference of young people to establish their own households and live independently, rather than living under one roof with their parents and grandparents (Liu et al 2001, Liu et al. 2003a).

**Demographic and socioeconomic background**

Recent economic soar in China has caused a series of changes in lifestyle of rural people. Hoping to raise the living standards by quickly containing population growth (1.265 billion in 2000), China has enforced a family planning policy, characterized by the one-child policy in cities and a relatively relaxed policy (2 children) in most rural areas. The Economic incentives and administrative penalties for out-of-plan births have made this policy successful in controlling population growth (Merli and Smith 2002). The "later, longer, and fewer" (wan xi shao) campaign has been implemented since 1970s, encouraging (requiring in some sense) that couples bear children at an older age (later), prolong the time between births of two consecutive children if more than one child is allowed (longer), and have fewer children (fewer), which developed into the more strict one-child policy later (Feng and Hao 1992). As a result, China's total fertility rate (TFR) dropped greatly since the end of 1970s: it was 3.0 in 1979 (Hussain 2002) and 1.8 in early 1990s, and could be as low as 1.6 (Wong 2001), which is far below the replacement level of 2.1 However, this low TFR still translates into an annual increment of 6.7 million people due to the huge population base, although the annual growth rate of population is low (0.54%; Hussain 2002).

The reduction of fertility would usually highlight the importance of migration. As the China's economy grows at a rapid annual growth rate of 7-10%, cities continues to have a growing demand for migrant labor for jobs shunned by urban residents. The domestic temporary migration, a timely outlet for rural surplus labor and opportunity for many farmers to earn much higher incomes than their original subsistence farming, has led to a separation of temporary migrants actual residence from their de jure resident, resulting in uncontrolled high fertility (Yang 2000). This migration–fertility linkage has drawn wide attention across demographers, sociologists, and policy makers.

With no exception in such a socioeconomic setting, Wolong Nature Reserve has some special characteristics. First, as a rural area with minority groups (75% of local population are Tibetans), Wolong had a policy to allow three children in the past, especially in some remote areas in the reserve. According to Liu et al (1997a), the fertility was 2.5 between 1975 and 1999. However, recent years have seen a draconian policy of 2 children per couple regardless of location and ethnicity. Second, standing as a "flagship" reserve in China, Wolong has received substantial domestic and international financial (technical also in some cases) support, and the local residents have some benefits (e.g., lower tax, some agricultural production subsidy) that are unavailable to people elsewhere. Last, the residents of Wolong Nature Reserve follow a rural lifestyle, characterized by satisfying their subsistence needs directly from forests and cropland. They grow potato and corn primarily to feed pig fodders, and raise pigs for meat consumption and sale to tourists. With the belief that pig fodders should be well cooked prior to feeding pigs, they use a large portion of their fuelwood to cook pig fodders each year. According to An et al. (2001), annual household fuelwood demand ranges from 8 to 30 $m^3$, depending on household size, household age structure, whether there is senior person, and the area of cropland used to grow corn and potato. Electricity, the likely substitute for fuelwood, is subject to problems such as relatively high price, unstable quality, and some degree of safety concerns. A study of switch probabilities under different socioeconomic conditions shows that lowering price, increasing voltage, and decreasing voltage can greatly encourage local residents to use electricity as a substitute of fuelwood, thus reducing forest degradation (An et al. 2002).

China has a decreased proportion of children (0-14) and an increased proportion of working-age (15-64) groups. In 1964, these two numbers were

40.4% and 55.1%; while in 1999, they were 23.9% and 68.4% (Hussain 2002). This decline was partly due to the family planning policy as described earlier. Wolong has similar trend, though we do not have data matching the same years. Based on the age structures in 1982, 1996, and 2000 (Figure 5.1), the average age of local residents increased from 1982 to 1996 with a decreased portion of the people belong to the 0-4, 5-9, and 10-14 age groups (Figure 5.1). Changes between the 1996 and 2000 age structures are not as obvious as those between 1982 and 1996, but we can still observe a decrease in the proportion of the people in the infant group (0-4 years). Overall, the groups that constitute the labor force (20-59) dominated the local population. It is reported that changing age structure would have significant impacts on local biodiversity: the more young adults live in Wolong, the more forest may be cut down (Liu et al. 1999a). Very likely, the panda habitats would be further degraded if the current trend continues.

In addition to age structure, the number of households under a certain population is also of great interests. Based on Liu et al (2003a), smaller household size would cause higher per capita resource consumption. Traditionally Chinese people were accustomed to the lifestyle of many generations under one roof (Liu et al 1999a, 2001, An et al. 2003a), but this tradition has been increasingly challenged by the young generations. Adolescents' leaving parental home and subsequent household formation has been viewed as a normal and natural phenomenon and extensively studied as an interesting topic to sociologists and demographers in Western societies (Vos

1989, Baanders 1996), while China is short of research on this topic. In rural areas of China, the matrilineal extended family is still the major pattern, and the majority of the elderly people tend to live with their children, sons in particular (Cooney and Shi 1999). The research by An et al (2003a), however, has shown that though the young adults in Wolong care about the adverse effects associated with leaving parental home (such as house chore and taking care of young children), many of them still prefer to live independently as long as resources (land and timber in particular) allow them to do so (An et al. 2003).

In the past, local young people moved out of the reserve through (1) marrying people outside the reserve (usually people of richer areas), and (2) going to college and residing in cities after graduation. According to Liu et al. (2001), the elder people in Wolong do not want to move out of the reserve due to various reasons such as lack of skills to make living in other areas and inability to adapt to outside environment. In early 1980s there were some emigration households through governmental subsidy, which have been viewed as unsuccessful effort (Liu et al 2001) because many of them moved back due to inability to find jobs or adapt to outside natural and cultural environment. However, parents and grandparents encourage their children or grandchildren move out through obtaining higher education. On the other hand, a small number of outside people move into the reserve each year and obtain permanent residence through marriage by law.

### Research goal and questions

All the above facts, to varying degrees, have implications for panda conservation. We are interested in how the changes in some demographic features (e.g., age structure, fertility) and socioeconomic factors could change panda habitats over time in a spatially explicit manner. A piecemeal treatment is obviously not effective because the underlying mechanisms and interrelationships among different subsystems are often ignored or not paid sufficient attention. On the contrary, it is necessary to put parts together and consider the interactions while making policies or taking actions for conservation purpose. This situation necessitates the goal of this research: change the socioeconomic and demographic factors in a spatial agent-based model and study how these factors impact the panda habitat as a result. The questions of interests include: (1) what demographic/socioeconomic factors have significant impacts on dynamics of panda habitat? (2) How such factors as electricity subsidy could conserve panda habitat over time? (3) Given changes on one factor or a combination of factors, how panda habitats will respond accordingly over time and space?

## Methods

### Model

- Conceptual framework

With an excellent study site and a wealth of data (See Section "Study site"), we have developed an Integrative Model for Simulating Household and Ecosystem Dynamics (IMSHED; see An et al. 2003b), which resorts to agent-based modeling (ABM) and geographic information systems (GIS). ABM is a methodology that predicts or explains emergent higher-level phenomena by tracking the actions of multiple low-level "agents" that constitute or at least impact the system behavior observed at higher levels. Agents usually have some degree of self-awareness, intelligence, autonomous behavior, and knowledge of the environment and other agents as well; they can adjust their own actions in response to the environmental changes (Lim et al. 2002). The methodology underlying ABM is called "object-oriented programming" in computer science, and C++ and Java are two of the most popular coding languages.

The model structure is illustrated in Figure 5.2. IMSHED views individual persons, households, and land pixels as discrete agents. The layer of dashed households in the dashed box represents households in Wolong landscape at a past time, while the layer of solid ones represents households in the same landscape but at a later time. Our introduction focuses on this layer.

First, all the existing households, symbolically called household A and household B in Figure 5.2, come from the past and will head into the future. This evolution includes many events: existing households may increase or decrease in size, dissolve, or relocate; new households may be initiated as individual persons go through their life history. Here life history events include: (1) education emigration. When the random number generator creates a number smaller than a parameter called college rate (0.0192, the probability of a young person going to college), then he/she moves out of the reserve. (2) Death. If the random number generator creates a number smaller than mortality rate corresponding to the person, he/she dies; otherwise survives and moves to the next year. (3) Marriage. A local male may move out of the reserve through marriage, marry an outside female into the reserve, or marry a local female. The decision is made by comparing a randomly created number with probabilities derived from empirical data. The counterpart for a local female is similar to this process. At a yearly basis, all the people are categorized into four groups: (1) young group for all less than 22 years old[11] and unmarried people (males and females), (2) single male group for all single male over 22 years old, (3) single female group for all single females over 22 years old, and (4) married group for all females and males who have spouses with them (Figure 5.5). Though the simulation and observational unit here is the household, individual information is contained implicitly as the household evolves.

The formation of new households is determined or influenced by psychosocial factors (An et al. 2003a). At each snapshot over time, the fuelwood demand and the probability that each household would switch from fuelwood to electricity are determined by a number of socioeconomic and demographic

[11] The average bride age at first marriage was around 22 years old in 1982 (Hussain 2002).

factors (An et al. 2001, 2002). The trees on the landscape, given no human interference, grow and die by themselves. Information regarding the type of species, growth rate, and total volume in each pixel is contained in the model. The interactions between humans and the environment are realized through fuelwood collection, as shown by the two arrows in Figure 5.2. A household, given a certain amount of fuelwood demand, goes to a certain pixel to cut fuelwood. Worth of mention are contextual factors that include policy, law, and geographical factors such as elevation and plant species are included in the model. They exert impacts on processes such as household formation and demand for electricity, and may ultimately impact panda habitat dynamics.

- Important model features

Following the above conceptual framework, some specific features (e.g., some socioeconomic and demographic parameters) are worthy of a brief introduction. Fuelwood consumption is calculated on a household basis in IMSHED. According to An et al. (2001), the fuelwood demand for a household consists of three components: (1) fuelwood for cooking, which equals 0.467xhousehold_size + 0.703, (2) fuelwood for heating, which equals 7.23 + 1.37xsenior_index—0 for households with non senior(s) and 1 for households with senior(s), and (3) fuelwood for cooking pig fodders, which equals 24.856xcorn_land_area – 0.338. Component (1) is a function of household size—since our model updates the size of each household on a yearly basis, this section is also calculated annually. Component (2) depends on our annual check of whether a household has a person over 60 years old: if there is, senior index is set to 1, otherwise 0. Component (3) depends on the area of the corn land, which was called corn/potato land because these two crops are usually grown together and both are primarily used as fodders. This switch probability is determined by the age, gender, and education of the household head, household annual income (household annual expense as a proxy, see An et al. 2002), current and hypothetical electricity prices, outage frequency levels, voltage levels, distance of fuelwood transportation, and location of the household under consideration (1 for Wolong Township and 0 for Gengda Township; An et al. 2002).

An important parameter in IMSHED is leaving parental home intention, which is defined as the probability that a "parental-home dweller" would leave parental household and set up a new household. A parental-home dweller include (1) a male who has no siblings, (2) a male who has only female siblings, (3) a male who is the youngest male sibling among brothers, (4) a female who has no siblings, and (5) a female who has only female siblings and is the youngest among these female siblings. IMSHED uses marriage age (22 years old as the default), number of children per couple, sibling interval (time interval between births of two consecutive siblings) to control the number and timing of births for each married woman. We do not consider some situations such as single-mothers or divorces because these types of phenomena are rare in Wolong (An, field observations).

Wolong has some young people who work in cities for seasonal temporary jobs. Most of them come back for the Chinese calendar new year (spring festival), some for help in agriculturally busy months, and few do not plan to come back due to many migration regulations such as the residence registration permit system (known as Hukou). These types of people are still considered as local population in this study. Some temporary workers, if they marry people in cities or other rural areas, do not come back. So the migrations have two legal approaches: going to colleges (including technical schools and some equivalencies) and marriage. To simulate migrations, we use stochastic processes to control number of out-migrants and in-migrants: if the random number generator generates a number smaller than any of the below rates in a given year, then the associate event would occur for that specific person under consideration. (1) College attendance rate: the ratio between the number of people who go to college and the total number of people between 16-22 years old in a given year; (2) female marry-out rate[12], the ratio between the number of females between 22-30 years old who move outside the reserve through marriage and the total number of people in a given year. (3) Male marry-out rate: similar to the above definition. (4) Female marry-in rate: the ratio between the number of males of 22-30 who bring outside females into the reserve through marriage and the total number of people in a given year. (5) Male marry-in rate: the ratio between the number of females of 22-30 who bring outside males into the reserve through marriage and the total number of people in a given year. All the above factors are defined in An et al. (2003b).

[12] Some females marry people outside the reserve through network other than the temporary relations as mentioned above, e.g., introduction by relatives who migrated earlier. This is also true for other migration types as follow.

**Data preparation and integration**

Our data used for model construction consist of the 1996 agricultural operation and contracting data (Wolong Nature Reserve 1997) and 2000 population census data (Wolong Nature Reserve 2000). All these individual-based data are arranged by households, covering all rural people in the reserve, including name, personal ID, ID of the household that this person belongs to, gender, age, education, kinship relation to the household head, and so on. But the 1996 data do not have interpersonal relations in relation to household head as the 2000 data do; we derive these relations based on the data in 2000 as shown below.

It is important to simulate life history of each person because events possibly occurring for one specific person (Figure 5.3) are likely to impact decisions of other people. Based on data in the kinship relation to the household head in 2000 population census, we use an index system to represent these relations (Figure 5.4): each household head (either male or female) is given a relation index of 100.10, and his/her spouse 100.11. His/her siblings, if living in the same household, are given 100.20 (100.21 for spouse), 100.30 (100.31 for spouse), and so on. Since we have not found any household with more than 9 siblings living under one roof, and the current law does not allow any family to have more than 9 children in the future, this indexing method works well. The parents get indices of 90.10 for father and 90.11 for mother, 90.20 for uncle/aunt and 90.21 for spouse if they live together, and so on. The children get 110.10 (110.11 for spouse), 110.20 (110.21 for spouse), and so on.

Based on the relations between individuals in 2000 data, we derive the relations for the 1996 data. For example, household A had 4 individuals in 2000, and they were the household head, his wife, one child of 3 years old, and his father. In 1996, there were also 4 individuals—but a woman of three years younger than the household head with the same family name, not the child, was in the household. So we assume that this woman was the sister of the household head, and moved out of the household between 1996 and 2000. We assign her a relation index of 100.20, indicating she was sibling of the household head in 1996. We are also interested in the reason why she moved out—it could be that she (1) moved out of the household only and was relocated in another household in the reserve through marriage; (2) moved out of the reserve through marriage; (3) died accidentally; and (4) went to college. Based on the current household registration system and population census policy, only situation (1) can be determined based on our available population data of Wolong because the same person should be still registered in the reserve except that she was in another household. Situations (2), (3), and (4) are more difficult to deal with, though. We put all the people similar to this situation together (say 30 people total), and then used the age-based mortality rates to determine how many of them may have died, and used the rate of going to college to determine how many may have gone to college. The remaining number should be the number of people who went outside the reserve through marriage.

Doing this way, we calculated the number of males who migrated into Wolong through marriage, the number of females who migrated into Wolong through marriage, the number of males who migrated outside Wolong, and the number of females who migrated outside Wolong between 1996 and 2000. These numbers are 9, 40, 9, and 58, respectively. Using the number of males who migrated into Wolong through marriage divided the average population size 4179, we have a rate of 0.00043, indicating that for each unmarried male person, the probability that he would move out of the reserve through marriage is 0.043%. Similarly, we calculated the other three rates of 0.19%, 0.043%, and 0.28%. These numbers are used later in simulation (Section "Demographic and socioeconomic background").

**Simulations**

We simulate the impacts of socioeconomic factors for 20 years, and those for demographic factors for 30 years. The rationale for doing so is: (1) we have found that changes in many demographic factors need longer time to exert impacts on panda habitats (An et al. 2003b). (2) Theoretically, 30 years could allow the young children (e.g., under 5 years old) to grow up and experience all the possible events such as going to college and marriage. In some situations where two generations are theoretically needed to watch the associated effects, we conduct the simulations for 50 years. For instance, if we increase the time (years) between two consecutive siblings, it takes time for the birth-delayed sibling to experience all the possible events (e.g., going to college, deciding to leave parental household) and lead to changes in habitats through increased/ decreased or earlier/delayed fuelwood demand.

Electricity factors (price, outage level, and voltage level) are found significant in affecting panda habitat dynamics, and the default values for each household are set to be equal to the current values of these variables based on our survey data in 1999 (An et al. 2002). For testing how changes in these three variables would impact panda habitats, we set a 0.05Yuan decrease for electricity price, a one level increase for voltage level (no more than level 2, the highest level in our study), and one level decrease for outage level (no less than 0; 0 for low, 1 for medium, and 2 for high for both voltage and outage levels). Also significant is the leaving parental home intention (An et al. 2003b): the default value is 0.42, indicating that 42% of the "parental-home dwellers" (See Section "Introduction") would prefer to live independently. As a consequence of the decline in fertility, the proportion of elderly people will grow (Zimmer and Kwong 2003). Doubled with an increasing preference for leaving parental home and initiating their own households, this pattern of aging population may offset the decreasing trend in number of households induced by the lowered fertility. We set this parameter to 0.63 and test how the number of households and panda habitats would respond.

A few interesting demographic factors are worth testing for their potential impacts on panda habitat, and the associated rationales are as follow. (1) Total fertility rate (TFR): controlling fertility is a major policy in China to control population. The default value is set to 2.0 persons per couple based on the policy enforced in Wolong. We change it to both 1[13] and 3.5[14] for a stricter population

[13] This conforms to the one-child policy in China.

control policy and a loose control, which could be caused by either an ineffective government implementation of the control policy, or extra births of those migrating people who intentionally go to other places to bear and give birth to children. The motivation for more children lies in the fact that the more children a person has, the more financial and instrumental (e.g., assistance to conduct daily house chore) support they can obtain from their children when they get old; there is no insurance or pension system for rural workers (Zimmer and Kwong 2003). (2) Marriage age: the higher the marriage age, the fewer people within a certain period of time given the same fertility rates. We change its value from the default (i.e., 22) to 28 years old, which is consistent with the "later" component of the "later, longer, and fewer" campaign. Some other developing countries (such as India; see Sushama 1996) have used this approach to curb population increase. (3) Sibling interval (time interval between births of consecutive siblings): the longer this interval, the fewer people within a certain period of time given the same fertility rates. This conforms to the "longer" component of the "later, longer, and fewer" campaign. We set its default to be 3.5 based on our empirical data (Figure 5.5), and change it to 5.5 years as a policy test. (4) Colleague attendance rate: we change it from 0.0192 to 0.05. (5) Female marry-out rate (the ratio between the number of females between 22-30 years who move out of the reserve through marriage and the total population size at a given year): we change it from 0.0028 to 0.20. All the above factors are defined in An et al. (2003b). (6) As indicated by Figure 5.6, the majority of the females have born

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[14] This number reflects a situation where rural people would bear more children to meet their subsistence needs.

their last child prior to 50, so 50 is the default value for the maximal age to give births. However, as economic incentives and technical supports (such as contraceptives) are implemented, this number may undergo great decline. As such, we change it from 50 to 40.

In addition to studying the impacts of individual factors described above, we examine two scenarios with all the above factors considered simultaneously: a desirable scenario with the factors taking values that would benefit panda habitats, and a undesirable scenario with the factors taking values that would degrade panda habitats. Table 5.1 gives what these two scenarios include. Doing so may provide some insight into the range of possible trajectories of panda habitat conversion, and its consequent effect on the likelihood of giant panda survival.

**Significance test**

In order to examine whether the changes in the dependent variables (population size, number of households, and panda habitats) are significant, we run the model 5-10 times (depending on variability of the outcomes) and record values of the dependent variables. The length of demographic simulations is 30 years for one run. For the socioeconomic simulations, we run over 20 years because this length is enough for these factors to show their impacts on panda habitats. For some demographic factors, we run the simulation for 50 years to allow for the associated impacts observable. We then use two-sample t-test in S-

Plus to compare the results (called one set) thus obtained under one parameter value (or a set of parameters) with those under status quo scenario. The null hypothesis is that the averages of both sets are equal, and the alternative hypothesis is that one set of values is not equal to (two-tailed), greater, or less than (one-tailed) the other set, depending on the specific situation under consideration. All the tests are conducted at the 95% significance level.

## Results

The predicted population sizes do not have significant changes (Figure 5.7 (a)) under the changes in five socioeconomic factors, i.e., status quo condition, a 0.05 Yuan decrease of electricity price, one level increase in voltage, one level decrease in outage level and an increase of leaving parental home intention from 0.42 to 0.63. The associated t values (with the p –values in parentheses) are -01.002 (0.3457), -0.8525 (0.4187), -1.3303 (0.2201), and – 0.0143 (0.9889). These small t values and large p values indicate that changing these socioeconomic factors (scenarios 2-5 in Figure 5.7(a)) do not significantly impact population size over 30 years. However, scenario 5 (an increase of leaving parental home intention) has significant impact on the number of households (Figure 5.7 (b)) because the t value is –17.2099 (negative sign stands for the status quo values smaller than the ones observed after the parameter modification; the same hereafter) and the p value is 0.0000, which means that the probability that the null hypothesis (both are equal) is true is nearly zero.

Regarding panda habitats (Figure 5.8), all these four factors (corresponding to scenarios 2-5) are significant in that all the p values are very small (less than 0.001). In terms of panda habitats, all the changes in above four factors have caused significant changes, and the associated t values are –44.4163 (0.000), -20.7142 (0.000), -30.7965 (0.000), and 6.0952 (0.0001).

Changes of demographic factors all have significant impacts on population size (Figure 5.9 (a)) in that the t values for scenarios 2-7 are –21.2295, 4.9535, 2.4591, 15.742, 16.4429, and 2.645 with all their p values close to 0.0000. These changes include an increase of the number of children per couple from 2.0 to 3.5 (scenario 2), an increase of the marriage age from 22 to 28 (scenario 3), an increase of the age difference between two consecutive siblings from 3.5 to 5.5 (scenario 4), an increase of the college rate from 1.92% to 5.76% (scenario 5), an percent of 20% of the women between 22 and 30 moving outside Wolong (scenario 6), and the upper birth age from 50 to 35 (scenario 7). Scenario 2 (an increase of the number of children per couple from 2.0 to 3.5; Figure 5.9 (b)), however, does not have significant impacts on number of households with t = 0.27966 and p = 0. 7869. Regarding impacts on habitats, scenarios 3 and 7 are not significant with t = -1.6302 (p = 0.1417) and t = -0.332 (p = 0.7484), respectively. All the other four scenarios (2,4, 5, 6) have significantly increased panda habitats (the factor of birth interval is only significant at 90% level with p = 0.0958), though the absolute magnitudes are relatively small, ranging from 1.0 to 2 $km^2$ (Figure 5.10).

The desirable and undesirable scenarios show that (1) the difference of impacts on population size, number of households, and panda habitats between these two scenarios is escalating with time (Figure 5.11 (a) and (b), Figures 5.12-5.15). (2) At the end of year 30, there could be a difference of approximately 3850 people, 900 households, and 52 $km^2$ panda habitats between these two scenarios. When the spatial distributions of panda habitats and households are in consideration (Figures 5.14 and 5.15), it is more straightforward to see the great impacts caused by demographic and socioeconomic factors. Also, Figures 5.14-5.16 show that the spatio-temporal dynamics of panda habitats could differ greatly due to different socioeconomic and demographic parameters.

## Conclusions and discussions

Above analyses show that human demographic and socioeconomic factors play a very important role in affecting the spatio-temporal patterns of panda habitats. Some demographic factors, however, do not have significant impacts on the panda habitats. This is largely related to the time frame. From Figure 5.12, we can see an increasing magnitude of the impacts caused by human factors, though either the desirable or the undesirable scenario is a combo of many factors. To see if this escalating-impact trend is true for the two insignificant factors as mentioned above (marriage age and upper birth age), we run the model over 50 years with marriage age to be 22, upper birth age to be

35, respectively. Then the average panda habitats are 549.76 $km^2$ (status quo scenario), 553.78 $km^2$ (marriage age 28), and 551.71 $km^2$ (upper birth age 35), all significant at 95% level. Though the absolute is not large (usually 2-4 between individual scenarios), it still would cause great habitat degradation when other factors are combined such as the undesirable scenario, especially in the long run.

In this study we treat many demographic factors as exogenous factors for modeling simplicity purpose. An example is fertility, which could be affected by many other socioeconomic and demographic factors as well. For instance, female education, economic equity (e.g., job opportunities) between males and females, household income, and financial equality between rich and poor households could affect fertility rates to varying extent (Daily 1996). In microeconomics where the concept of household production function is introduced and used, the incomes and time of household members are combined to produce an array of commodities that yield utilities and welfare. As economy grows and the value of human time rises, households tend to have fewer but "higher-quality" children who receive better health care and higher education (e.g., Schultz 1981). However, as the reserve is a nature reserve where the primary goal is to protect giant pandas, other endangered species, and the associated ecosystems, it should be cautious to take the path of economic growth as elsewhere. On the other hand, as suggested by Liu et al. (1999a), youth emigration through providing higher chances to local farmers' children or grandchildren might be an effective way to save pandas while not sacrificing local people's well-being. In the short run, providing subsidies in using electricity and increasing electricity quality may work well. Also worthy of mention is household income, which is not included in the factors affecting panda habitat due to lack of data. It is reported to be an important factor in determining many household decisions such as fertility (e.g., Klawon and Tiefenthaler 2001) and land use (Perz 2001). In the future, inclusion of this factor may improve the analyses.

Our findings in this research are consistent with what Liu et al. (1999a) and Axinn (2003) have found: (1) human demographic factors (age structures in particular) play an important role in affecting biodiversity conservation. One example is that a decline in fertility would save the panda habitats greatly, as shown in Section "Results". (2) Migration, especially through high-level education (college or technical schools) and marriage, is an effective, efficient, and socially acceptable approach to conserving wildlife habitat or biodiversity in broader sense. (3) Non-family organizations or services (electricity subsidy and assistance in our case) can reduce direct consumption of natural resources and could be integrated into programs in environmental protection, biodiversity conservation, and wildlife preservation. Additionally, our findings suggest that family planning, in terms of timing of getting married, number of children to have, the time between consecutive children, is very important in conserving natural resources and thus has critical significance in human-environment studies. This finding also has great policy implications in an undeveloped rural setting such as Wolong, where people still follow a subsistence-oriented lifestyle and need more children as labor force. It may lead to social resistance if a policy of strict birth control (e.g., one child per couple like the situation in cities) is implemented. However, policies encouraging late marriage and longer interval between children should have more public acceptance, especially when economic incentives (such as electricity subsidy or tax reduction) are bundled with such a family planning program.

It is therefore concluded that human demographic and socioeconomic factors are critically important in making polices for panda conservation. We recommend that a program for providing electricity subsidy and assistance, and emigration through higher education and marriage be initiated and implemented for panda conservation. Actually, while the research is in progress, the reserve government has built a new hydropower plant and we hope cheaper electricity could be provide to local people. As to the existing family planning policy, it should be implemented and monitored, as any increase in fertility would cause severe habitat loss. Given a policy or a set of policies, we can predict the associated response of panda habitats over both time and space. From this perspective, this research provides a decision support tool for scenario preview and risk analysis. Aside from these types of practical purposes for panda conservation, this research is also oriented towards using an integrated approach to explore the impacts of socioeconomic and demographic factors on the environment. As is often the case in many other places or for other purposes such as protection of other species, complexities in many coupled society-biodiversity systems have kept some socioeconomic and demographic factors (often intertwined with each other) and their interactions from being explicitly studied. Though the socioeconomic and demographic factors and their specific interactions may differ from place to place, the perspectives and methods used in this research could still be useful. For more effective and efficient wildlife or biodiversity conservation, it is crucially important, thus highly recommended, that socioeconomic and demographic factors, along with more individual-level information if possible, be integrated into whatever research or conservation activities.

**Figure legend (Some of the figures are color images)**

Figure 5.1. Age structures in 1975, 1996, and 2000.

Figure 5.2. Model structure of IMSHED.

Figure 5.3. Simulation of possible events in the life history of each person.

Figure 5.4. Kinship relations among people in a household. The dotted persons imply spouses who may or may not exist at the time of simulation. For the meanings of the numbers, see text in Section "Data preparation and integration".

Figure 5.5. Distributions of age differences between consecutive siblings.

Figure 5.6. Number of mothers who bear their youngest children at varying ages.

Figure 5.7. Predicted population size (a) and number of households under five socioeconomic scenarios. Scenario 1: status quo condition; scenario 2: a 0.05 Yuan decrease of electricity price; scenario 3: one level increase in voltage; scenario 4: one level decrease in outage level; and scenario 5: leaving parental home intention from 0.42 to 0.63. The error bars display one standard deviation.

Figure 5.8: Predicted panda habitats under five scenarios. The scenarios are the same as those in Figure 5.7.

Figure 5.9. Predicted population size (a) and number of households (b) under six demographic scenarios. Scenario 1: status quo condition; scenario 2: number of children per couple from 2.5 to 3.5; scenario 3: marriage age from 22 to 28; scenario 4: age difference between two consecutive siblings; scenario 5: college rate from 1.92% to 5.76%; and scenario 6:

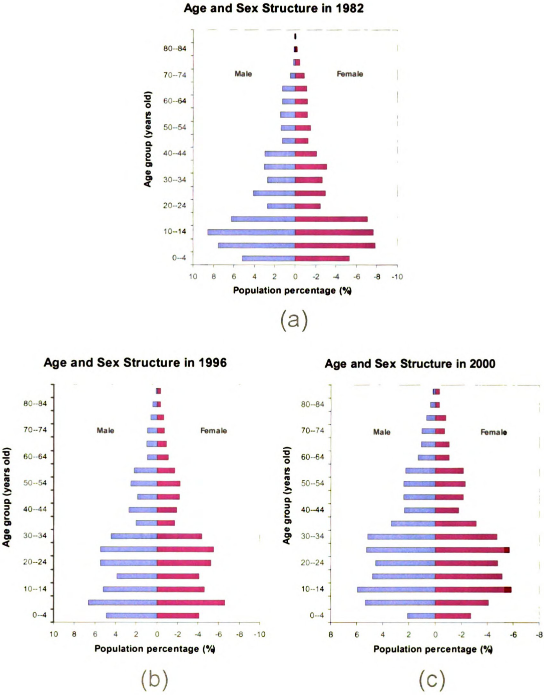



Figure 5.1. Age structures in 1975, 1996, and 2000.

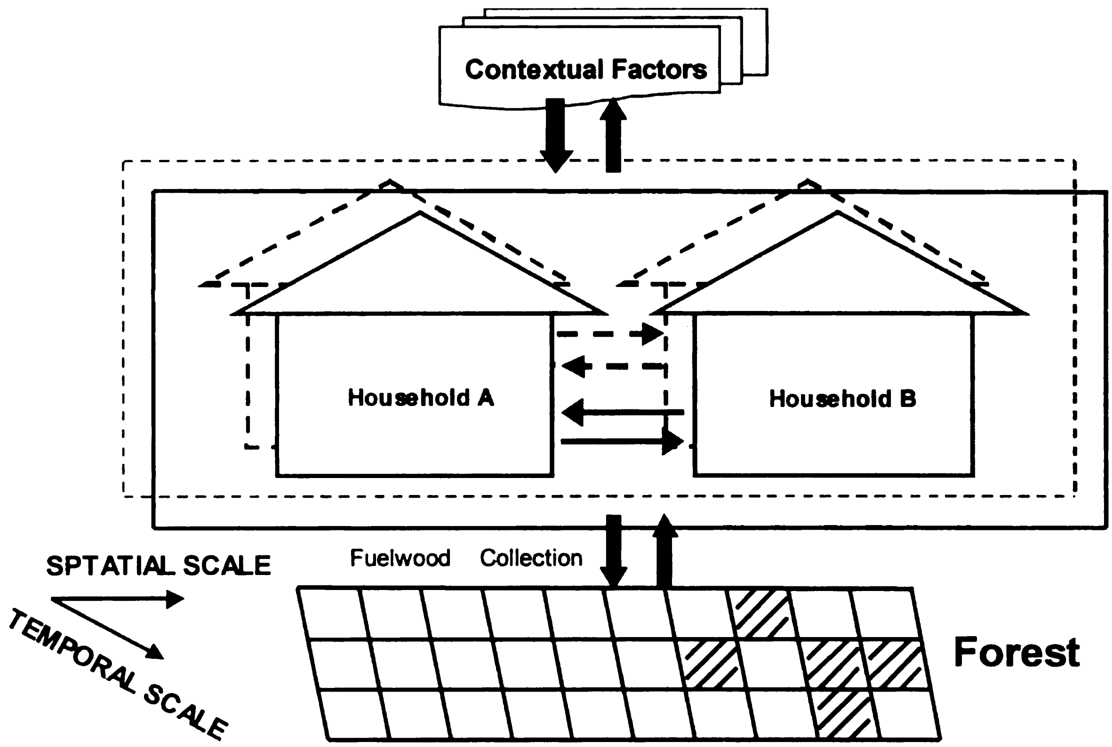



Figure 5.2. Model structure of IMSHED.

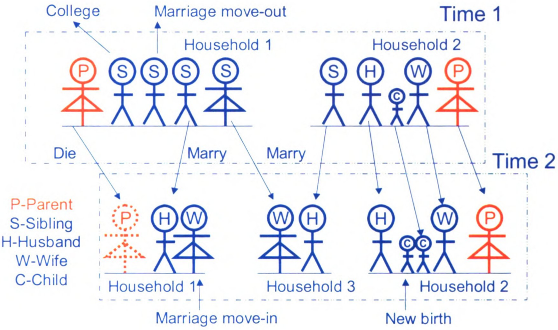



Figure 5.3. Simulation of possible events in the life history of each person.

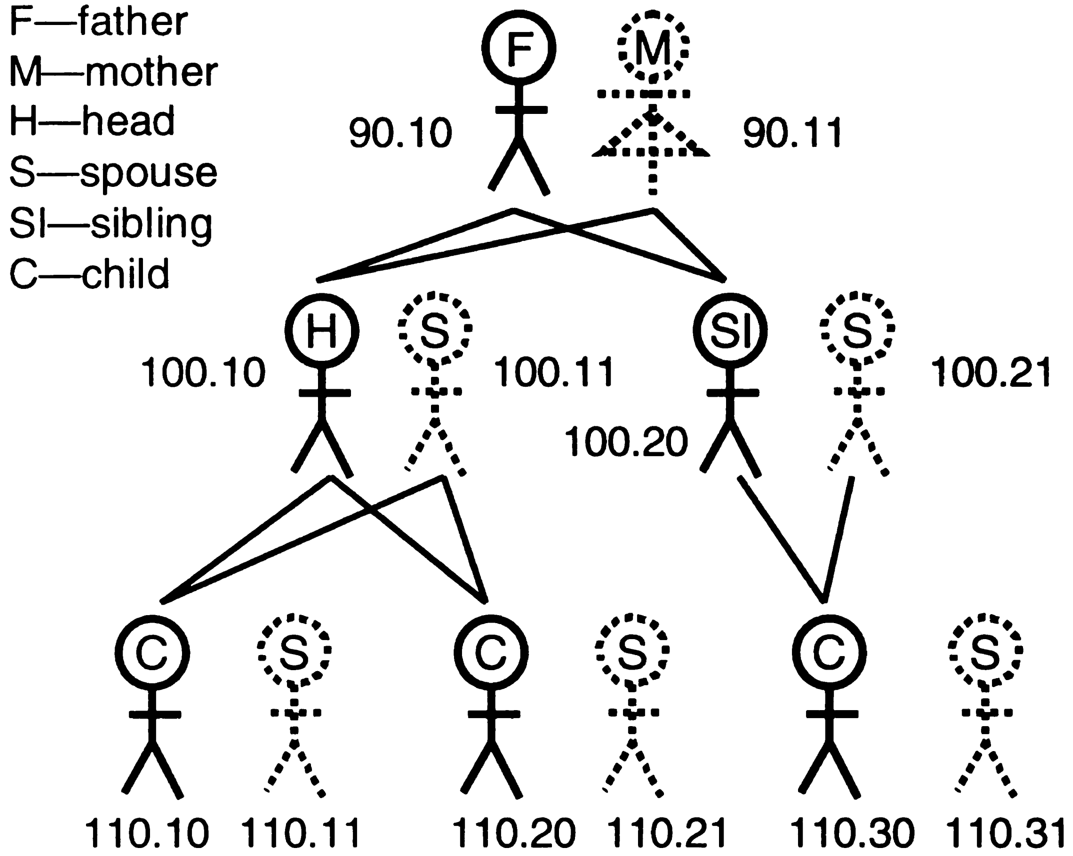
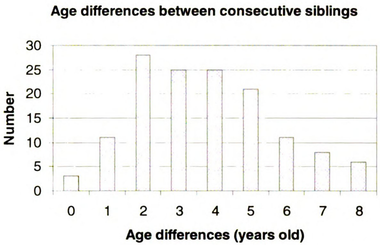
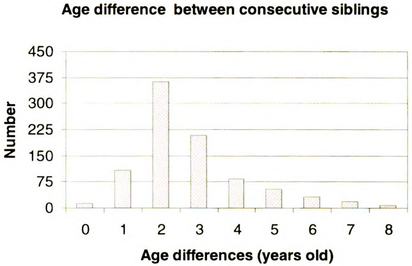



Figure 5.4. Kinship relations among people in a household. The dotted persons




(a) Age > 22




(b) Age < 22

Figure 5.5. Distributions of age differences between consecutive siblings.

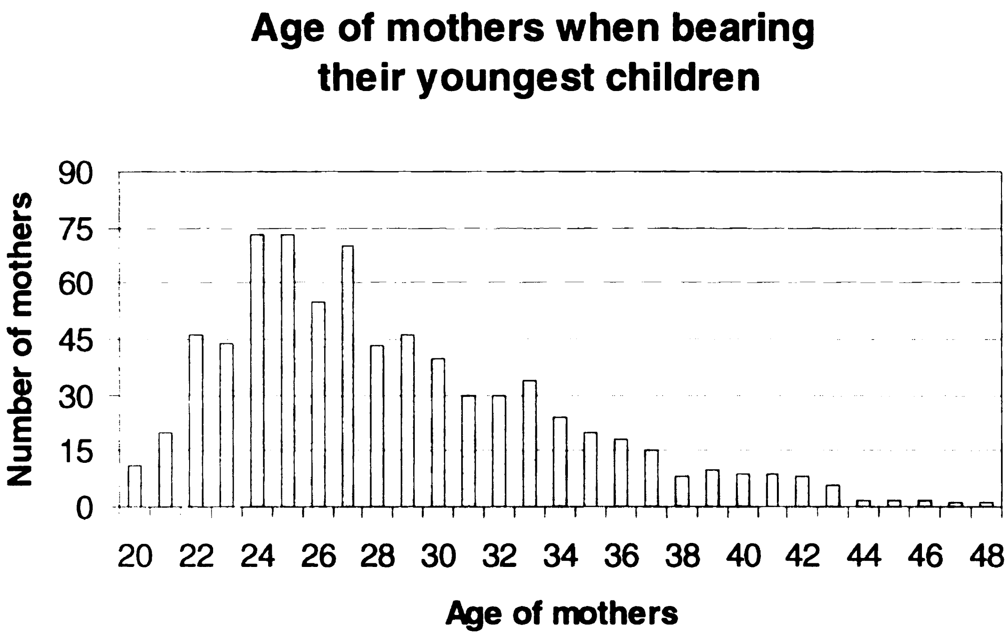
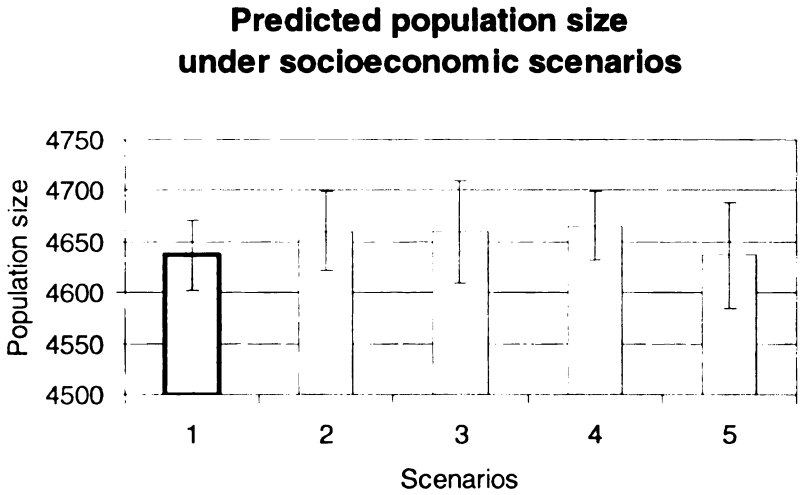
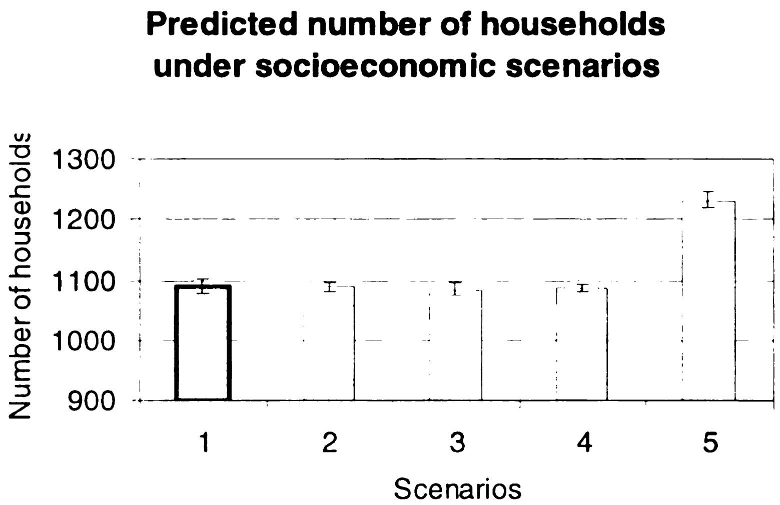



Figure 5.6. Number of mothers who bear their youngest children at varying ages.




(a)




(b)

Figure 5.7. Predicted population size (a) and number of households under five socioeconomic scenarios. Scenario 1: status quo condition; scenario 2: a 0.05 Yuan decrease of electricity price; scenario 3: one level increase in voltage; scenario 4: one level decrease in outage level; and scenario 5: leaving parental home intention from 0.42 to 0.63. The error bars display one standard deviation.

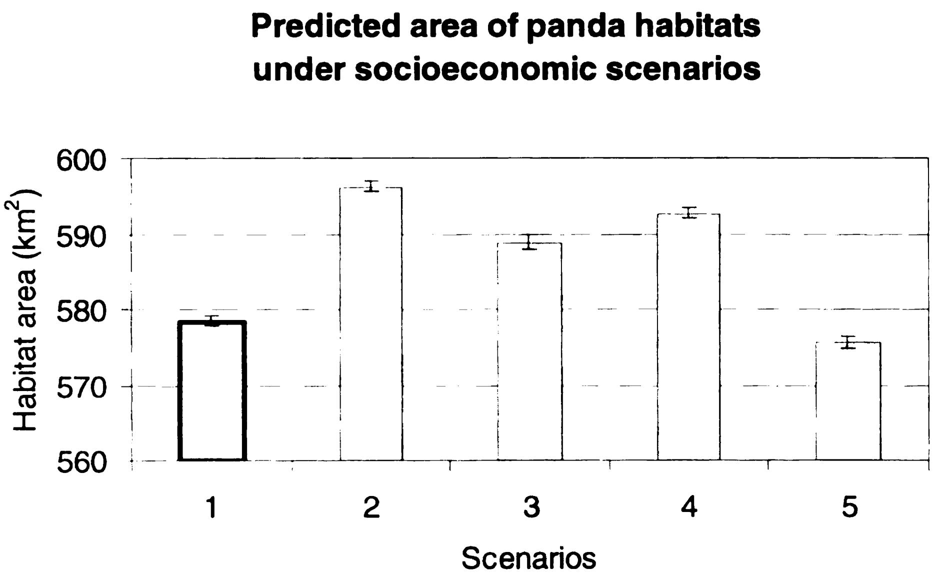



Figure 5.8: Predicted panda habitats under five scenarios. The scenarios are the same as those in Figure 5.7.

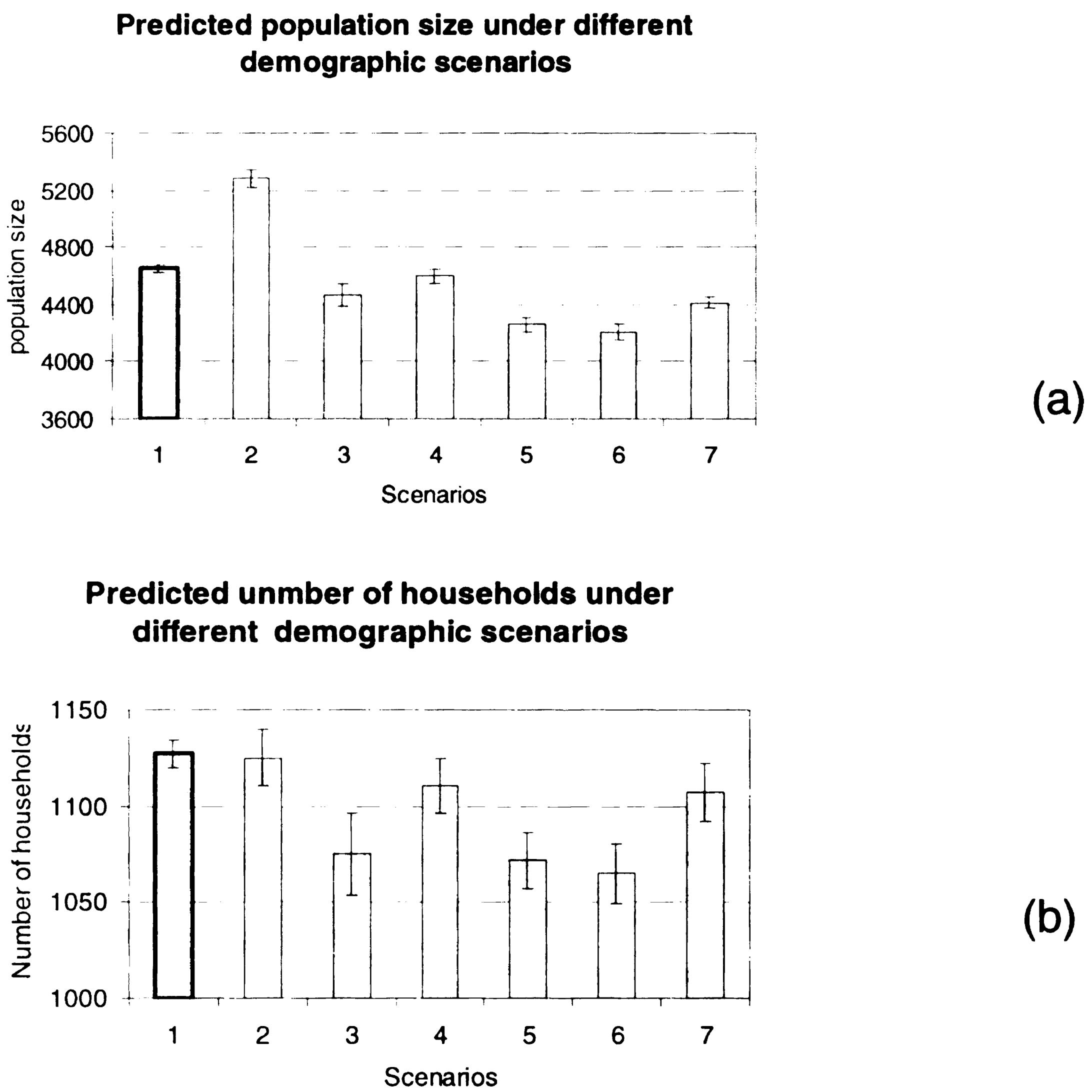



Figure 5.9. Predicted population size (a) and number of households (b) under six demographic scenarios. Scenario 1: status quo condition; scenario 2: number of children per couple from 2.5 to 3.5; scenario 3: marriage age from 22 to 28; scenario 4: age difference between two consecutive siblings; scenario 5: college rate from 1.92% to 5.76%; and scenario 6: 20% of the women between 22 and 30 moving outside Wolong. The error bars display one standard deviation.

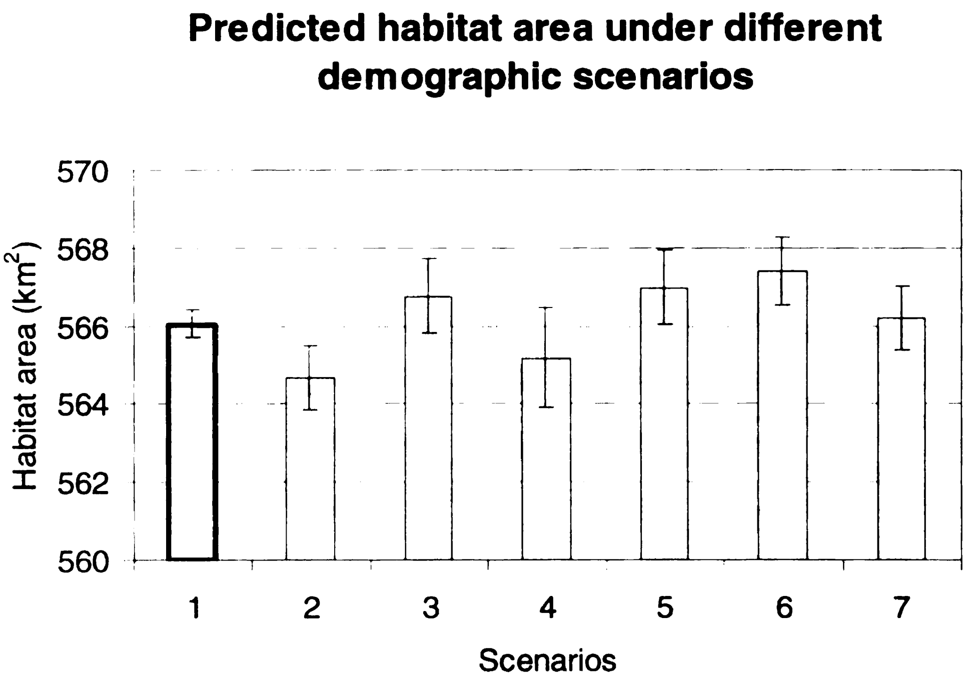
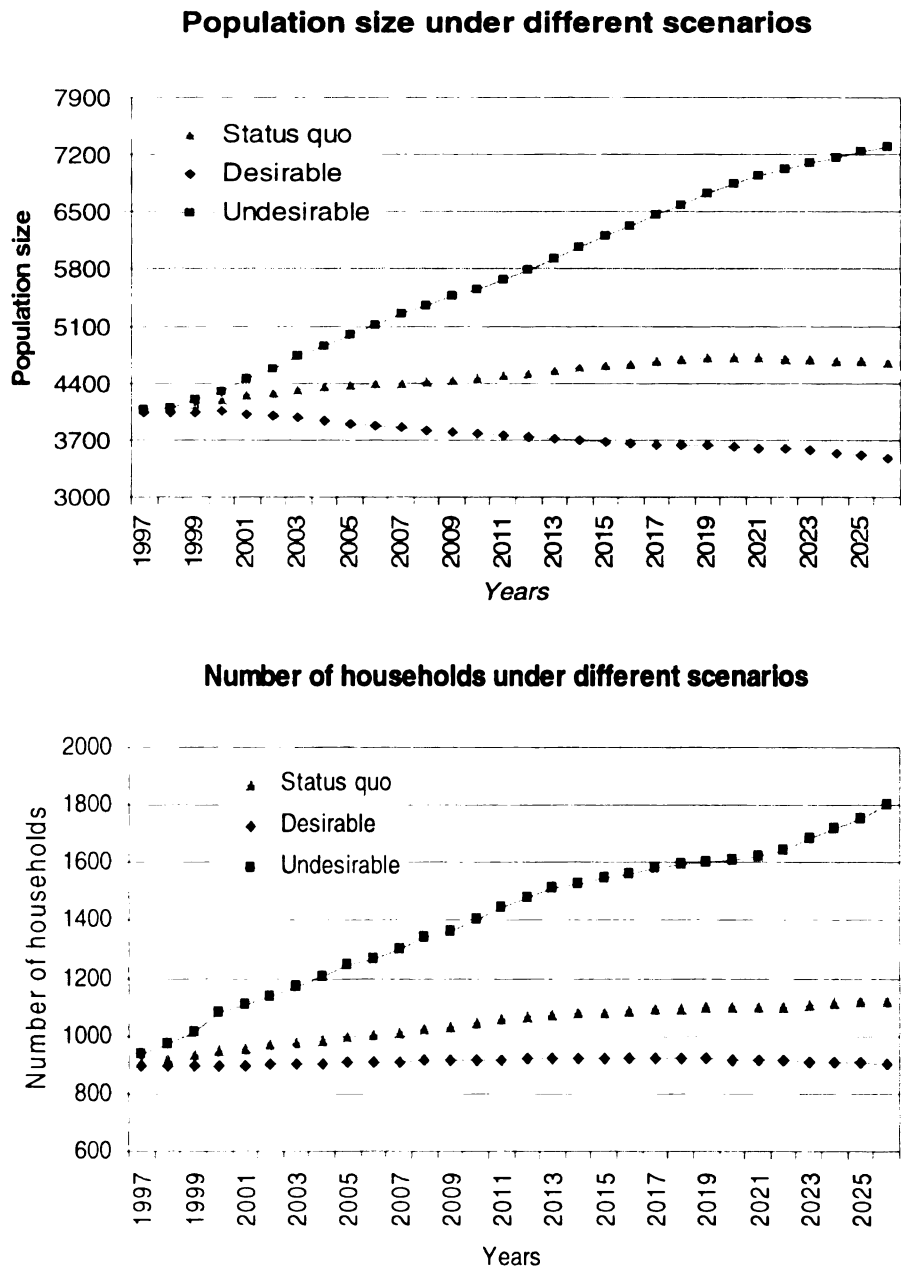



Figure 5.10. Predicted panda habitats under six scenarios. The scenarios are the same as those in Figure 5.9.




(a)

(b)

Figure 5.11. Predicted population size (a) and number of households (b) under status quo scenario, desirable scenario, and undesirable scenario. For definition of desirable and undesirable scenarios, see text in Section "Demographic and socioeconomic background".

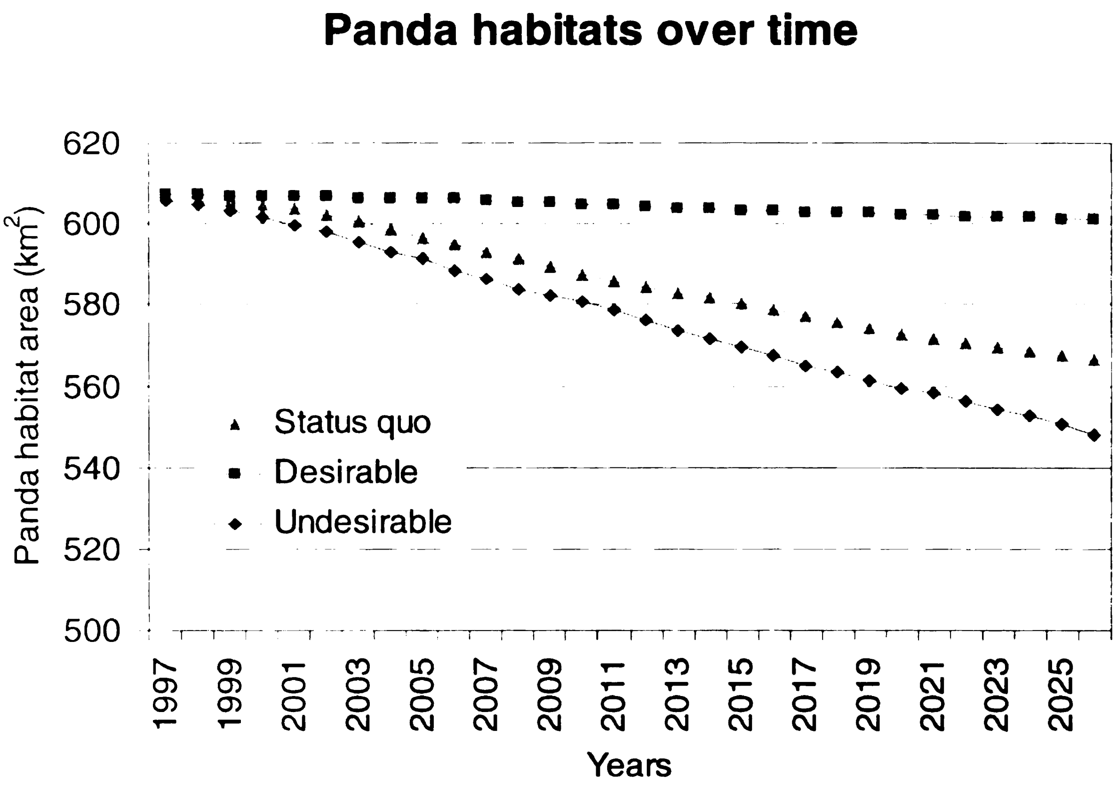



Figure 5.12. Predicted panda habitat under status quo scenario, desirable scenario, and undesirable scenario. For definition of desirable and undesirable scenarios, see text in Section "Demographic and socioeconomic background".

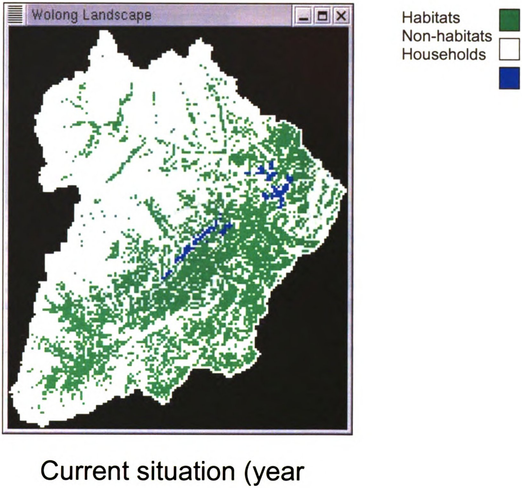
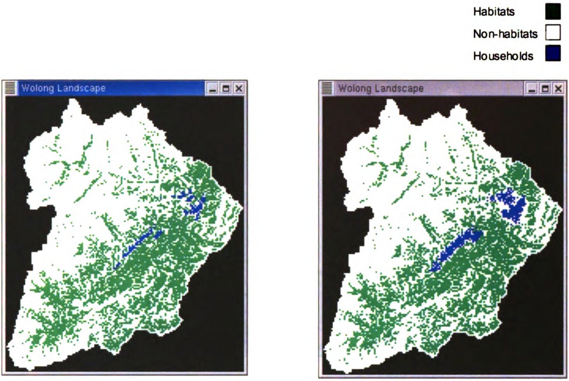
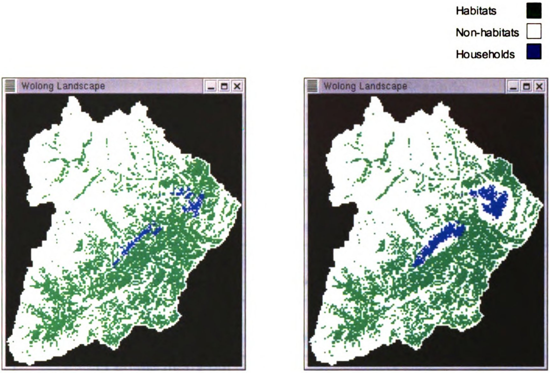



Figure 5.13. Distribution of panda habitats and households in 1996.




(a)—Desirable scenario (2011) (b)—Undesirable scenario (2011)

Figure 5.14. Predicted distribution of panda habitats and households in 2011 under (a) desirable situation, and (b) undesirable situation. For definition of desirable and undesirable scenarios, see text in Section "Demographic and socioeconomic background".




(a)—Desirable scenario (2026) (b)—Undesirable scenario (2026)

Figure 5.15. Predicted distribution of panda habitats and households in 2011 under (a) desirable situation, and (b) undesirable situation. For definition of desirable and undesirable scenarios, see text in Section "Simulations".

Table 5.1. Definition of desirable and undesirable scenarios. The first numbers in the spaces below are the default values in the model, and the second values are those used in the associated scenarios.

| | Contents | Desirable scenario | Undesirable Scenario |
|---|---|---|---|
| Electricity | Price | 0.05 Yuan decline | Program canceled |
| | Outage levels | One level decrease | |
| | Voltage levels | One level increase | |
| Migration rates | Leaving parental home intention | 0.42 → 0.21 | 0.42 → 0.95 |
| | College rate | 1.92% → 5% (16-20 youth) | 1.92% → 0.0% |
| | Female marry-out rate | 0.28% → 20% | 0.28% → 0.0% |
| Family planning | Fertility | 2.0 → 1.5 | 2.0 →5 |
| | Birth interval | 3.5 → 5.5 | 3.5 → 1.5 |
| | Marriage age | 22 → 28 | 22 |

# CONCLUSIONS AND SYNTHESIS

The goal of this dissertation research was to study how the household demographic feature, human needs, attitudes, activities, and government policies impact the spatio-temporal pattern of panda habitats, which contributes to an increasing agenda called sustainability science (Clark 2002), where the human-environment interactions are the major concerns. The interdisciplinary and across-scale (time and space) nature of this research has made it necessary to use a multitude of models and methods, including structural equation modeling, agent-based modeling, and extensive fieldwork. Some of them have been seldom used in this type of human-environment studies, such as the structural equation modeling. Below are several major features regarding the new framework and approaches developed in my dissertation to integrate across-disciplinary models and data, and thus study the complex mechanisms underlying many socioeconomic and ecological processes.

First, this research links demography and individual socioeconomic choice data to spatio-temporal dynamics of biodiversity. It has long been recognized that human activities have exerted great impacts on the environment, especially the biodiverisity and the crucial services it provides, but past efforts mainly focused on the aggregation level using traditional equation-based approaches. These approaches are good to detect some general trends, but ignore individualistic properties (often regarded as outliers, averaged or even discarded). Doing so works well in many situations, but would lose accuracy or even cause misleading results when these individualistic properties are common in the system under consideration.

With fast and large-memory computers, it has been practical to capture, store, handle, and analyze a large amount of individual-based data, especially spatial data when geographic information systems (GIS) are used together. In this regard, agent-based modeling with GIS input has contributed significantly to this research. The model developed in Java-Swarm could provide some reusable routines for similar research projects. However, this technique (ABM plus GIS) is still immature because of: (1) the lack of commonly-accepted protocols in dealing with some types of agents and their interactions with other agents or the environment, (2) Incomplete integration with existing GIS and thus inefficiency in using some powerful functions such as query and path-finding, and (3) the need for extensive programming.

Second, this research establishes some innovative ways to collect and process multi-disciplinary data. For instance, to obtain the coordinates of all the households, one way could be to GPS all the households. This way would be very time-consuming and manpower consuming. What I did with my colleagues was to sample a number of households that are located across the reserve, and measure their coordinates with GPS. Then using these households (and some other types of points as well) as groundtruthing points, four remote sensing (IKONOS with 1 m resolution) images were georeferenced, where locations of nearly all the households are identifiable visually. From these IKONOS images, the coordinates of all the remaining households were derived. Of course, doing so is subject to some factors that may cause inaccuracies, such as the distribution of the groudtruthing points[15] and the quality of the imagery[16]. So it is desirable to collect some additional points in the future for (1) more extensive groundtruthing, and (2) measuring those questionable households.

Moreover, with household ID and/or the name of household head as unique identifier, all the socioeconomic and demographic data are linked to the households spatially explicitly. This linkage provides a good basis for later spatial modeling and analysis. However, inconsistencies arise when the spelling of a household head' name is different in 2000 census data from that in 1996 agricultural survey data, the two demographic and socioeconomic data sets upon which this research heavily replies. In the future, survey data need to be double checked about who is the household head, and the correct name spelling in Han Yu Ping Ying (pronunciation system for Chinese characters).

Third, this research is characterized by integrating some methods that are not usually used in ecological studies into the entire systems model. An example is the use of structural equations modeling (SEM) in studying the home leaving intention and behavior. The results are partly integrated in the IMSHED model because the SEM model does not provide a probability of staying at the original home or establishing a new home, as the econometric model in Chapter 2 does. But this SEM model does provide some qualitative information regarding this behavior that is used in IMSHED, such as perceived resources play an important

[15] Theoretically, it is ideal that the points are distributed evenly across the entire reserve. But this is very difficult, if not impossible, due to the hard topography or even inaccessibility in some areas.
[16] For example, if there is cloud that blocks the household, then that household cannot be identified from the map. Or if a household is in the shadow of a big tree, it is also hard to decide if there is a household in the shadow, or where the household is located.

role in making the decision. A future direction is to build some structure equations into the systems model.

One of the great strengths in SEM lies in the fact that it allows for a variable to be both exogenous and endogenous in different equations, which are evaluated simultaneously (Bollen 1989)[17]. This property may find important applications in ecological studies, where various habitat features and biophysical features are often interdependent (Dumortier et al. 2002), unsuitable to enter into multiple regressions equally (Stapleton 1995). For a simple hypothetical example of GIS-based biodiversity study, let *Y* be biodiversity index (e.g., probability of an indicator species' presence), *A* be vertical vegetation structural diversity, *B* be pH of soil, *C* be organic matter of soil, and *D* be elevation. We can test a set of hypotheses written in the form of structural equations (such as $Y=\alpha A+\beta B+\gamma C$, $A=\eta B+\varphi C+\lambda D$, and $B=\phi C+\rho D$, all Greek letters are coefficients) simultaneously. Aside from excellent overall goodness of fit, SEM lends more flexibility to test different relationships (thus helpful in finding some ecologically-meaningful mechanisms), to discern statistically significant habitat features (this may trigger studies on their ecological meanings), and to allow for indirect but correlated features (such as *D*, possibly insignificant in common regressions) to be included without violating the uncorrelatedness requirement.

[17] Aside from this property, SEM minimizes the difference between the sample covariances and the covariances predicted by the model rather than minimizing functions (say, sum of squares) between predicted and observed individual values; and all regression models are special cases of SEM (Bollen 1989). See An et al (2002b) for an example.

Practically, the IMSHED model is helpful for local policy-making in Wolong Nature Reserve because of the link between human individuals' needs and activities, public policy and panda habitat dynamics. For instance, it can help the reserve mangers to answer questions such as: (1) given a 0.05 Yuan subsidy in electricity price, how much panda habitat could be saved in a future time? In which places? (2) Given a policy for out-migration (e.g, through providing more chances of higher education to children of local farmers as suggested by Liu et al. 2001), how many people and number of households will be in Wolong at different future times?

In summary, this integrative framework could be useful in many other places, where interdisciplinary (both data and methods) integration could be accomplished through the features described above (e.g., bottom-up approach, data collection and integration), especially when various properties and actions are needed to be bundled together at individual levels to explain the emergent phenomena at higher levels. Furthermore, it could contribute to the increasing growth of theories and methods in complex systems studies.

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