ENVIRONMENTAL IMPACTS OF THE SOCIOECONOMIC FACTORS AFFECTING ENERGY USE FOR RURAL FAMILIES AND MIGRANT WORKERS IN CHINA.

by

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Dr. John Zhai

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The final copy of this thesis has been examined by the signatories, and we
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Abstract

Watrous, Abigail Thomas (Ph.D., Civil Engineering)

Environmental Impacts of the Socioeconomic Factors Affecting Energy Use for Rural Families and Migrant Workers in China.

Thesis directed by Associate Professor Dr. John Zhai and Professor Dr. Gregor Henze

Based in a desire to better understand the socioeconomic and environmental impacts of energy use as millions of people migrate from rural China into the cities, this dissertation sought to evaluate what are the key factors involved in how rural Chinese families and migrant workers make their energy choices for home heating and cooking. An additional research goal was to determine if education about renewable energy effects energy consumption patterns. One output of the research was an agent-based model to predict how these factors will affect China's energy consumption patterns over the next 25 years.

By creating, administrating and evaluating the Beijing Migrant Workers' Energy Survey, analyzing the Tsinghua Rural Energy Survey data set, and incorporating these results into an agent-based model, we are able to predict solid fuel use and income levels for rural, urban, and migrant populations in China over the next 25 years.

Data from the Tsinghua Rural Energy Survey was used to calculate the top factors impacting rural energy use and connections between education and solid fuel use, and income and solid fuel use. Data from the Beijing Migrant Workers Energy Survey was used to evaluate factors impacting fuel use by migrant workers, how their energy use changes when they move to the city, and connections between their education level and solid fuel use, and income and solid fuel use. Results from analysis of both data sets were incorporated into a new agent-based model to predict solid fuel use over the next 25 years by rural, urban, and migrant populations.

Major findings were that the top factors influencing rural fuel use were location (north or south), yearly electricity expenses, education level, area of the home, and income. Understanding of renewable energy did not have a significant impact on solid fuel use, although overall education level did. Top factors influencing migrant workers' energy use were how many years they had lived in Beijing, and the type of fuels they used for cooking and heating back home.

To the King of ages,
immortal, invisible, the only God,
be honor and glory forever and ever.
Amen.

1st Timothy 1:17

但愿尊贵，
荣耀归与那不能朽坏不能看见永世的君王，
独一的神，直到永永远远。阿们。

提摩太前书 1:17

For Mom, Dad, David, Gwyneth and Vivienne

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CHAPTER 1
INTRODUCTION

1 Introduction

China is a large and complex country that is facing huge challenges and opportunities in the areas of environmental protection, water, energy, education, human rights, and migration. One of the largest factors shaping the landscape of China today is migration. As millions of people migrate from the countryside, towns, or smaller cities into rapidly growing large cities, their entire lives are turned upside down, and the fabric of China will be forever changed.

The goal of this research is to better understand the factors affecting how people use energy in rural China and how these factors change with migration into the cities. One output of this work is an agent-based model that can effectively predict the probability of solid versus non-solid fuel consumption from home heating and cooking for rural Chinese families and migrant workers. The future of rural China is migration. Understanding how migrant workers use energy will allow us to better grasp the upcoming changes China will face in terms of energy consumption, environmental pollution, and personal health impacts for rural families and for the migrant workers who are building modern China.

China has a population of around 1.3 billion people, and more than 60 percent, or more than 700 million people, live in rural areas. This rural population uses a variety of fuel types for heating and cooking, often using solid fuels, such as wood, biomass, cornstalks, dung, and notably, coal. As rural people's incomes increase, they tend to move towards a fuel mix that includes non-solid fuels, such as LPG and electricity.

From a public health perspective, the primary distinction between fuels is solid (coal, wood, biomass) and non-solid (gas, electricity, LPG) fuels. Non-solid fuels have a significantly worse impact on human health. The World Health Organization has identified indoor air pollution from use of solid fuels as a serious disease risk, and found that indoor air pollution (IAP) is responsible for the deaths of 1.6 million people per year (WHO, Indoor Air Pollution and Health Factsheet, 2005).

Health effects of indoor air pollution from solid fuels are acute respiratory infections in young children, chronic obstructive pulmonary disease, and lung cancer. In 2000, about 3 percent of the burden of disease from solid fuels was estimated to be due to solid fuel use. Additional suspected health outcomes are tuberculosis, cardiovascular disease and adverse pregnancy outcomes, but these have not yet but verified. Therefore, the disease burden is likely much greater than estimated (Smith K. , Indoor air pollution from household use of solid fuels., 2004, pp. 1435-1436). Additional secondary health effects related to use of solid fuels can include physical strain and time spent collecting biomass, and dangers associated with coal mining (in China, often in small, unregulated or illegal mines) (Smith K. , Indoor air pollution from household use of solid fuels., 2004, p. 1456).

In rural China, families are faced with many challenges such as poor health, lack of education, comparatively low incomes, and extreme stresses to the family structure as young people migrate into the cities to work in factories or service industries rather than farming. McKinsey and Company released a report “Preparing for China’s Urban Billion” showing four different scenarios for the rapid growth of Chinese cities in the next 15-20 years. They predict that more than 350 million people will be added to China’s urban population by 2025, with one billion people living in China’s cities by 2030. This will create 221 Chinese cities with more than one million people (as compared to only 35 cities of this size in Europe today). According to their predictions migrants will account for over 240 million of those more than 350 million people (McKinsey and Company).

China as a whole is struggling with environmental issues as it experiences extreme rates of economic growth. In 2007 The *New York Times* released a series of articles highlighting these environmental challenges. Entitled 'Choking on Growth,' it had ten parts, including coverage on the water crisis, Three Gorges dam, and energy. This series stated that outdoor air pollution is a serious issue, and air pollution levels in Beijing regularly exceed World Health Organization standards (New York Times, 2007). Hourly readings of $PM_{2.5}$ for January 3, 2011 at one point reached 286ppm, with an Air Quality Index (AQI) of 336 (BeijingAir, 2011). This falls into the 'Hazardous' level of the Air Quality Index as defined by the Environmental Protection Agency (AirQualityIndex). The World Health Organization guidelines for $PM_{2.5}$ are 25µg/m3 for a 24-hour mean (WorldHealthOrganization, 2008).

China recognizes the challenges it is facing, and is taking its energy and environmental problems seriously. However, the magnitude of the task is staggering. The government developed a Renewable Energy Law in 2005 and updated it in 2009 (Martinot, Renewable power for China: Past, present and future., 2010). The government set the ambitious goal of obtaining 15 percent of national energy from renewable resources by 2020 (China Daily, 2009), and is moving rapidly to install renewable energy capacity[1]. China's wind turbine manufacturing market is the largest in the world, and from 2004-2005, its wind power grew thirty-fold (Martinot & Junfung, Renewable Energy Policy Update for China, 2010).

While the government is addressing environment and energy issues from policy and technical approaches, many people in rural areas are being left out of these advances. China has recently raised their poverty line. At the end of 2009, there were 35.97 million rural people living under the poverty line based on Chinese standards, but based on the World Bank definition of poverty

[1] Total renewable power capacity reached 226 GW in 2009, which included 197 GW hydro, 25.8 GW wind, 3.2 GW biomass, and 0.4 GW grid-connected PV. This is more than 25 percent of total installed power capacity of 860 GW (Martinot and Junfung, Renewable Energy Policy Update for China, 2010).

as living on less than $1.25 a day, there were 150 million people living in poverty in China (Zhu, 2010). More important than which definition is used, is the reality that there are millions of poor rural people in China, many of whom are using solid fuels, which have detrimental impacts on their and their children's health.

Since 2007, China has been the world's leading producer of carbon dioxide. China is also the world's greatest energy consumer. What happens in terms of energy use in China has implications for the rest of the world in terms of global air pollution, environmental health, and climate change.

As rural Chinese migrate into the cities, the energy patterns both of the older people left at home and the younger people living in the cities will change. As millions of people change their living patterns and increase their standard of living, energy consumption is also expected to increase. As the overall population switches from rural to urban, it would be easy to assume that as people migrate to the cities they begin to use cleaner forms of energy. Research has validated the 'Energy Ladder' principal of development – that as people's incomes increase, they tend to use more sophisticated, or more non-solid, types of fuels, and this has been seen in rural China as well. However, given the challenges facing migrant workers in China, this is may not always be the case, as migrant workers generally have lower income levels than their urban counterparts.

Predicting energy use is a challenging feat, and it is especially difficult in the case of a complex and rapidly changing country like China. Research in international development and other fields has also additionally shown that human behavior is one of the most challenging aspects to model and predict. A dynamic model of these behavioral patterns of consumption may allow prediction of changes in energy use both in rural China and in these rapidly growing cities. These changes in energy consumption levels will have significant environmental impacts as

China attempts to grow rapidly while still making a concerted effort to develop environmental controls.

1.1 Overview of the Study

While many researchers have looked into issues of migration in China, indoor air pollution from solid fuels, and energy modeling for the future of energy use, it appears that no one has yet examined how migrant workers in China use energy and how their energy use differs from the rural and urban populations.

In order to better assess how energy use in China will change over the next 25 years, and how the health of migrant workers will be impacted by their energy choices, we need to understand how this unique group of people is using energy within the context of moving to the city.

The purpose of this project is to understand how rural families make their energy choices; how migrant workers use energy; and the connections between education, income, and solid fuel use for migrant workers and how that differs from the rural population. Results from this analysis are then used to build an agent-based model to predict how these factors will play out within the changing structure of China during the next 25 years.

1.1.1 Research Questions

The three research questions fall into the categories of understanding the current situation in rural China and predicting how it will change in the next decade and a half, taking into account the huge migration that is and will continue taking place. These questions are:

1. What are the key factors involved in how rural Chinese families and migrant workers make their energy choices for home heating and cooking?

2. Can we effectively predict how these factors will affect China's energy consumption patterns over the next 25 years?
3. Will education about renewable energy effect energy consumption patterns?

1.1.2 Research Methods

The method of investigation was to conduct first-hand fieldwork in China in the form of observation, written surveys, and video interviews. Additionally, a pre-existing rural energy data set from Tsinghua University was utilized. Data analysis was conducted using Excel to assess correlations between education and income, and regression using a generalized linear model (GLM) in R (statistical analysis software) was conducted to assess probabilities of solid fuel use based on input factors.

The Tsinghua Rural Energy survey is based more on facts of families' housing type and energy use (rather than opinions on energy use and energy choices) and it is a rich source of data from around 4,000 rural families in both northern and southern China. The survey was conducted by university students in 2006 and 2007 and asked questions about housing type, window-to-wall ratio, energy use, income, education, fuel use and many other questions.

In the summer of 2011 191 written surveys of migrant workers in Beijing were conducted in order to better assess differences between their fuel use in their home towns and Beijing, and the connections between education, income and migration.

Furthermore, an agent-based model was developed to predict solid fuel use among rural, urban, and migrant populations in China over the next 25 years. This model was created using results from the summer 2011 survey of migrant workers in Beijing and the pre-existing Tsinghua Rural Energy data set. GLM results from R and education-income correlations from

Excel were incorporated within the model and overall results analyzed using a Monte-Carlo approach.

The author was fortunate to live and work in China for two and a half years, first as a National Science Foundation (NSF) East Asia and Pacific Summer Institute Fellow in the summer of 2007, then continuing on as a University of Colorado Benjamin Brown Award recipient until August 2008. In the summer of 2009, she returned to China for an additional 14 months as a Fulbright Fellow, and in 2011 spent seven weeks conducting summer fieldwork under an NSF Doctoral Dissertation Enhancement Project grant.

In Beijing a partnership was created with Dr. Xudong Yang and his Rural Energy research group at Tsinghua University, the leading technical university in China. Dr. Yang was extremely gracious in mentoring and introducing the author to challenges facing rural China, and also provided access to the Tsinghua Rural Energy survey data which proved invaluable in assessing relationships between solid fuels, education, and income.

Additional fieldwork included conducting a rural survey in Shanxi province outside Taiyuan city, a written survey of migrant workers in Beijing, in-depth written interviews in Er He Zhuang village outside of Beijing, video interviews of migrant workers in Beijing, a small survey of biomass pellets users in Huirou District outside of Beijing, and photographic documentation of rural life and energy use in Shanxi, Henan, Yunnan, Sichuan, and Guizhou provinces.

My Fulbright fellowship included creating and teaching renewable energy curricula to fifth grade students in Beijing and Colorado. This curriculum was taught in China both at a local Chinese school and an international school, and in Colorado taught at a Boulder Valley School District elementary school. The Fulbright program also included a four-month long immersion Chinese language program in Beijing. While research assistants helped with conducting surveys in Mandarin and with translation, this language program gave the author the linguistic foundation needed to informally converse with interview and survey subjects, and to conduct simple surveys in Mandarin personally.

Data presented here is approved under the University of Colorado's Institutional Review Board (IRB), Protocol #10-0161. This includes the Summer 2011 data set (191 written surveys along with video interviews) and the pre-existing Tsinghua Rural Energy data set.

1.2 Background Information

1.2.1 Development Issues of Rural China

Rural China is varied and complex. Economic developments of recent years have led to shifting dynamics in many areas: income levels, fuel use, and family living situations. Challenges to sustainable development are numerous: water shortages, deforestation, environmental degradation, building of dams, new power lines, and the emergence of cell phone and internet technologies that link people to the cities wirelessly[2]. The central government has promoted the rhetoric of "Develop the West" while at the same time millions of rural Chinese migrate to the cities, with their young people unlikely to return (Seligsohn, 2010)[3].

Rural populations often struggle with poverty, lack of access to education, health challenges, and environmental degradation. The Millennium Development Goals give a good overview of issues affecting China and other developing countries. The eight goals are to: ensure environmental sustainability; eradicate extreme poverty and hunger; achieve universal primary education; promote gender equality and empower women; reduce child mortality; improve

[2] Thanks to Eleanor Dougoud for helping to shape the author's perspectives on China (Dougoud, 2010).
[3] Deborah Seligsohn mentioned a study that said when young people leave their rural areas they are unlikely to return.

maternal health; combat HIV/AIDS, malaria, and other diseases; and develop a global partnership for development (World Bank).

One of the biggest development issues for rural China today is migration. While in 1980 only 100 million people lived in cities, Deng Xiaoping's policy changes in the decade following allowed the "biggest and fastest migration in history and more than 400 million farmers moved into towns and cities. The story of modern China is the story of that movement" (Watts, 2010). Migration has torn apart the traditional family structure for many families, and while it promises hope of a better life, in many cases it has brought sadness and confusion as migrant workers face discrimination and suffering as they fight for that better life.

The following gives an overview in visual form of some of the many challenges facing rural China. Issues that have a similar cause are grouped together, such as poisonous coal and fluorosis, or migration and lack of access to education (Watrous A. , 2011).

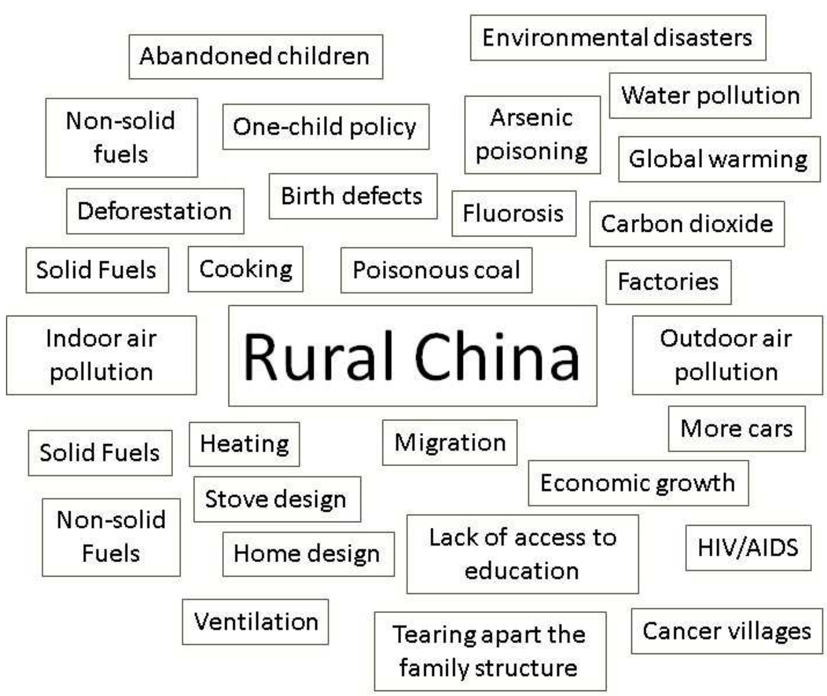

Figure 1: Concept map of challenges facing rural China

1.2.2 Current Rural Energy Technologies

A range of technologies are already being deployed in rural China, some of which are more modern and some of which are quite ancient. Technologies are available in many rural areas are: traditional and improved Chinese Kang, passive solar design, improved home insulation, solar hot water, solar electric, biomass pellets, improved cookstoves , and biogas digesters . One aspect that makes modeling rural fuel use in China challenging is that most families use a combination of fuels for cooking. For example, one family could use a combination of coal briquettes in a small stove, an electric hot pot, and occasionally LPG to cook their meals. The table below divides rural heating and cooking technologies into solid and non-solid fuel types. Solid fuels are generally considered to have more harmful health effects than non-solid.

Table 1: Rural heating and cooking technologies

Rural Heating and Cooking Technologies	
Solid	*Non-solid*
Chinese Kang (traditional heated bed)	Biomass digesters
Coal stove (honeycomb coal)	Solar electric
Coal boiler (lump coal)	LPG for cooking
Cooking with biomass	Gasification
Use of improved stoves	Electricity for cooking
Biomass pellets	Solar hot water

In the early 1980s to mid-1990s China conducted the National Improved Stoves Program (NISP), considered to be the "most impressive organized rural energy intervention in human history", which installed over 180 million improved stoves (Junfeng & Smith, 2007, p. 23). This is area of rural energy development in which China has been extremely proactive. An extensive independent review of effectiveness of the NISP was conducted with the goals of evaluating implementation methods used to promote the stoves, evaluating the creation and marketing of commercial stoves around the same time, and measuring program impacts at the household level. To achieve these goals a survey of government agencies and enterprises, as well as a large household survey were conducted. A number of journal articles were published on difference facets of the review project, and an 'NISP Dissemination Workshop' was held in Beijing in January of 2005 to share the results (University of California at Berkeley School of Public Health). Improved cookstoves can be an effective public health tool, although not all improved stoves lead to decreased exposure to air contaminants: "Not all the improved stoves resulted in benefits on all levels, however, and it is possible, therefore, to implement policies with the best intentions for alleviating the burden of collecting fuel, which may actually, result in increased exposure of the population to health damaging pollutants and increased global warming contributions" (Edwards, Smith, Zhang, & Ma, 2005, p. 1). This lesson should be taken to heart when implementing any biomass technology. Great care must be taken to ensure that implementation of a new biomass technology benefits the health of all its users, while considering environmental effects as well.

One common sources of solid fuel use are Chinese kangs, which are a traditional elevated Chinese bed, often made of cement, which connects to a stove at one end and a chimney at the other. Solid fuel, often biomass, is used to heat one end of the bed (often at the same time cooking a meal) and the heat and smoke travel through baffles under the bed and out the other end. This effectively provides cooking energy and space heating at the same time, and the large thermal mass of the bed releases heat throughout the day or night. This helps heat the home and provides a warm place to sleep. Other types of kangs are not connected to a stove, but have a hole at one end where coal or wood can be burnt. Use of kangs is especially significant in the cold northern climates, where the kang is often the warmest spot in the home. Some kangs are right next to the stove, and sometimes there is a wall between the kitchen and the bedroom and thus between the kang and the stove. Challenges with the use of kangs include leakage of smoke into the room through the kang or through a non-existent or ineffective chimney, and possible burns from children sleeping near the fire.

Gasification systems are not designed for household-level use, but are best implemented on a village scale. This requires training and a supply of fuel oil for the initial burning of the biomass. These systems also require a distribution system for the gas, which can raise tensions within a community about how to prioritize access to the gas. Another concern with gasifiers is the possibility of carbon monoxide (CO) leaks. Since CO is odorless (Wilson, 2007), it can leak into homes and kill people without them being aware of its presence. There have been reported deaths of workers at gasification facilities. However, this concern could be ameliorated with use of inexpensive carbon monoxide alarms. Gasifiers do have the potential for significant electricity generation if they are on a large enough scale (Smith K. , 2007).

Improved biomass stoves can burn biomass directly, use the gas generated from a digester, or can be an example of very small-scale gasification. This gasification process can be seen for instance in the "Rocket Stove" types of stoves, which are designed to have the hot gases from combustion pass around the sides of the cooking pot, thus increasing efficiency and leading to decreased solid fuel use (Gold, 2007). Biomass pellets are being used in some areas of China, and have been tested in a pilot project in a village outside of Beijing. Dr. Li of Tsinghua University is conducting research and testing in the area of biomass pellet production and use by rural families.

As almost all of China becomes electrified, rural renewable energy opportunities will decrease, but the use of biogas digesters is expected to continue to grow. In Western China and remote areas, solar electric and wind could still be essential energy sources. Future village-level renewable energy programs will depend on government policies (and how they're implemented at the village level) (Martinot & Junfeng, Powering China's Development: The Role of Renewable Energy, 2007, p. 36).

In addition to simpler technologies available in rural areas, China passed an ambitious Renewable Energy Law in 2005 and is aggressively pursuing using more renewable energies, including wind, solar, geothermal, hydropower, and biomass and biofuels. Though China is pursuing renewable energy, the main energy supplier is definitely coal, and the nation "still intends to continue to get most of its energy from coal for decades to come." Due to continued migration and growth, emissions are predicted to increase for at least the next two decades (Magistad, 2010).

Suggestions by researchers for moving forward with renewable energy in China include developing local research and technology (including manufacturing, design, and skilled personnel), creating a research center similar to the United States' National Renewable Energy Laboratory, building international partnerships, monitoring pricing of renewables, and continuing development of renewable energy policies (Martinot & Junfeng, Powering China's Development: The Role of Renewable Energy, 2007, pp. 32-33).

1.3 Study Significance

The goal of this study is to determine the key factors impacting energy choice in rural and migrant China and use those factors to predict percentage of solid fuel use for rural, urban, and migrant populations in China within the next 25 years. This dissertation is unique because it takes a sociological approach to the problem of predicting solid fuel use and combines it with mathematical modeling from an engineering perspective.

Research for this study thus far has found that both rural people and migrant workers are indeed aware of the impact different energy types may have on their health at a basic level.

However, they are not aware of what renewable energy is, or which technologies they can best use. They are not well-versed in available methods to improve housing and are likely unaware of connections between energy use, housing retrofits and health impacts. The primary concern of rural people in making their energy choices seems to be health, followed closely by cost and ease of use.

The prevailing lack of understanding about renewable energy, details of how energy use can impact health, and need to evaluate how renewable energies can best be implemented by rural families presents a great opportunity for NGO and policy groups to focus on education. The author's work with young students demonstrates that attitudes toward and knowledge of renewable energy can significantly change after a few short lessons. The hope is that this approach will prove to be effective in helping rural and migrant adults learn about renewable energy and how it can be effectively used in their lives.

Analysis of novel Beijing migrant workers' energy survey data as well as the Tsinghua Rural Energy database and development of an agent-based model to predict percentage of solid fuel use in China has provided three major contributions.

1. Determined the key factors impacting rural Chinese families' energy choices
2. Clearly demonstrated that solid fuel use by migrant workers is directly linked to income, education, and location
3. Developed an agent-based model to predict solid fuel use by rural families and migrant workers in China

Data on the current status of rural China and the importance of education as well as a model that effectively predicts changes in rural energy consumption over the next few decades may allow development professionals and policy makers to more accurately plan intervention programs and policies that address the needs of rural families and migrant workers.

Additionally, decreases in emissions from coal and other solid fuels may decrease indoor and outdoor air pollution for rural China leading to environmental benefits and perhaps lower carbon dioxide emissions for rural areas. An understanding of changes in energy use patterns as rural young people migrate to the cities will help both rural and urban planners and policy makers prepare for the future as China's cities undergo rapid growth. Effective energy use policies for both rural and urban China can have worldwide implications for carbon dioxide emissions and global warming.

1.4 Chapter Descriptions

This dissertation is broken into seven chapters. The first chapter gives an introduction to the problem, research questions, and research methods used. The second chapter is a literature review covering four pertinent areas: indoor air pollution, energy and environmental challenges in China, migration, and mathematical modeling. The third chapter gives methods for the novel Beijing Migrant Workers Energy Survey and video interviews of migrant workers in Beijing in Summer 2011, as well as results of those surveys. The fourth chapter provides an overview of the Tsinghua Rural Energy survey and gives some results from regression analysis of that survey. The fifth chapter gives methods for development of the agent-based model and results of the model. The sixth and final chapter provides conclusions of the study.

CHAPTER 2
LITERATURE REVIEW

2 Literature Review

The literature review covers four main areas that are pertinent to the research questions and following sections. The first section covers indoor air pollution in China. The second covers energy and environmental issues facing rural China. The third details a number of challenges related to migration in China, and the final outlines some other approaches to mathematical modeling of energy use in China. The literature review ends with a brief explanation of how this work fits into the existing literature.

2.1 Environmental Challenges in China

2.1.1 Indoor Air Pollution in China

According to the World Health Organization, indoor air pollution is responsible for around two million premature deaths each year, mostly in developing countries. (World Health Organization, 2011).

In the past 15 years, work on indoor air pollution in China has included work on both health effects and control strategies. Research on health effects has included work on indoor air pollution and cigarette smoking, solid fuel use, COPD (chronic obstructive pulmonary disease), lung cancer, risk of neural tube defects, biomass and coal burning, polycyclic aromatic hydrocarbons, pulmonary adenocarcinoma, cooking fuels and stoves, respiratory health, asthma in children, and formaldehyde pollution. One recent study looked at the connection between indoor air pollution and blood pressure and found that $PM_{2.5}$ from biomass combustion may be a risk factor for increased blood pressure (Baumgartner, et al., 2011).

Studies more focused on intervention have examined indoor air pollution abatement scenarios, intervention measures, the global burden of disease, countermeasures, global warming, formative causes, and control policy[4].

2.1.1.1 Air Pollution, Behavior and Housing

One survey found that just knowing about the health risks from indoor air pollution was in itself not enough to change behavior[5]. If 'exposure behaviors' are tightly connected to every-day activities (as they clearly are in the case of home heating and cooking) and have additional beneficial effects for the family, and if 'alternative technologies and behaviors' are not easily available and affordable, behavior change may not occur. Implications of these findings are that each new technology should take into account the myriad of ways it might be used (since one older technology may be used for a number of applications), and how other technologies or methods might fill in some of those uses. Additionally, looking to resources outside of the home, such as community-level and regional infrastructures, for help with increased access to and implementation of new technologies is recommended (Jin et al, 2006).

Since multiple fuels and stoves are used within households in China, intervention programs need to take this into account. Multi-fuel use depends on both infrastructure and energy policies, with infrastructure including such issues as pricing, availability, and manufacturing (Jin et al, 2006). Multi-fuel use is a challenge mentioned by many researchers in the field (Sinton, et al., 2004). In one study, 78 percent of households were using more than one fuel type (Peabody, et al., 2005).

[4] Overview based on GoogleScholar search for allintitle: China indoor air pollution since 1996 on August 9, 2011.

[5] A survey was conducted in four provinces in China (Gansu, Guizhou, Inner Mongolia and Shaanxi) to look at connections between 'technology, user knowledge and behavior, and access and infrastructure in exposure to IAP from household energy use'.

Housing also plays an important role in indoor air exposure, as home use and design changes in different areas across and within different provinces. Some rural homes use traditional kangs (a traditional Chinese heated bed), some have gaps between their attic and the rooms below (allowing smoke from a chimney into the attic to return to the home), and some use the coal smoke from their stove to dry food which then absorbs pollution from the coal (Jin et al, 2006).

One advantage of working with the Tsinghua rural energy survey data is that the survey includes information about multiple fuels used for heating and cooking, as well as detailed data on housing type.

This work is important because it is able to tease out correlations between different factors and how they impact use of solid fuels for heating and cooking respectively. This is often difficult due to multi-fuel use in China so this work is significant in separating out fuel types, and separating out heating from cooking as well.

2.1.1.2 Interventions

Ezzati and Kammen provide an overview of research in the area of indoor air pollution from solid fuels and suggest areas to focus on and incorporate into future research. Some of their suggestions include incorporating exposure patterns into interventions, recognizing and planning for the fact that poor households often use multiple stoves and fuels, and longitudinal monitoring of how stoves behave and are used. They also suggest that intervention programs take into account impacts beyond merely exposure, such as societal and environmental impacts, and also encourage looking into factors related to possible local business opportunities connected to interventions (Ezzati & Kammen, 2002).

In 2002 a researcher identified and suggested areas needing future research were epidemiology (including cardiovascular disease in women, adverse pregnancy outcomes, tuberculosis and acute childhood respiratory diseases), exposure assessment (especially for large-scale and national level assessment), and interventions (improved stoves, better ventilation, behavior change, and better fuels). This author also points out possible connections between trying to reduce greenhouse emissions and also decrease solid fuel use (Smith K. R., 2002).

In an assessment of improved stoves programs, researchers found that China had been very successful in installing 'improved' biomass stoves and coal stoves in their National Improved Stove Program (NISP). Coal stoves still lacked flues, however, and so were not considered to be actually improved. One success of the program was causing these new improved stoves to then be viewed as the new standard for a 'conventional' stove in many areas. However, for almost all of the fuel and stove combinations, indoor air levels of PM_4 were still above the national standard (Sinton, et al., 2004). Health impacts were also evaluated as a part of the NISP evaluation study, and coal-fuel use was definitely connected with worse health (Peabody, et al., 2005).

2.1.1.3 Coal in China

The energy ladder concept is a key idea in air pollution work and has been written about in many sources ((Kaul & Liu, 1992), (Van Ruijven, Urban, Benders, Moll, De Vries, & Van Vuuren, 2008). The idea is that as households increase their income they climb the 'energy ladder' from more rough, solid fuels, such as dung, biomass, wood, or coal, up through several stages to more processed fuels, such as LPG, electricity, and gas. While the goal is for people to use cleaner fuels as their income increases, millions of people in China still use coal every day to cook and heat their homes. Truly, in China, "coal is king".

However, this coal can have contaminants within it that have severe consequences for human health. In China's Guizhou Province, arsenic in coal has been shown to cause arsenic poisoning, leading to such health effects as hyperpigmentation, hyperkeratosis, and squamous cell carcinoma. One method of transmission for the arsenic in this region may be drying chili peppers over the coal and then consuming them later. Other modes are likely through other contaminated foods, dust and poisoned indoor air. Fluorosis is another terrible disease caused by absorption of the fluoride found in coal, through drying foods over poisoned coal. Fluorosis affects more than 10 million people in Guizhou Province alone, as well as people from 13 other provinces or other areas. In China, black lung disease (coal worker's pneumoconiosis, or CWP) still affects a great many people –600,000 Chinese workers are estimated to be suffering from this condition, with numbers expected to rise each year (Finkelman, 2007).

Clearly this reliance on coal has come with a number of health-related costs to the Chinese population. An interest in decreasing these serious health impacts as well as better understanding what happens in the area of energy use as rural people migrate to the city has led the author to pursue this research.

2.1.2 Rural China: Energy and Environment Issues

Rural China has undergone tremendous change over the past few decades, including the founding of the Communist Party in 1949 and the replacement of the land tenure system by collectives, followed by the death of Mao in 1976, and then the reforms of Deng Xiaoping, which reversed many programs and reverted farms back to being family-run (Unger, 2002, p. 1). From 1950 to 1979 rural areas struggled with energy shortages, which led to deforestation and harming of the environment. By the end of this period rural energy consumption was just 19 percent of urban use. Toward the end of this period, policy measures were passed to install biogas digesters, but due to lack of management and technical support, many of these failed after just a few years (Luo, 2004).

China's first national seminar on rural energy was held in 1980. 1980 to 1990 saw a focus on national policies to promote reforestation, household and industry energy efficiency, and renewable energy. Some of these key policies were reforestation (via designation of land for fuelwood forests), improved cookstoves, improved efficiency of industry (including boilers and kilns), increased production at rural coal mines[6], and rural electrification (via increased grid connection and use of small hydropower). Promotion of cookstoves started in 1983, and by the end of 1999 a reported 189 million households had had new stoves installed (Luo, 2004).

Economic reform began in 1978, and had a definite impact on property rights. By the mid-1990s firms were being privatized, and new privately-owned firms were being allowed in areas where publicly-owned firms had existed before. By 2001 China was "simultaneously making the transition from agriculture to industry and from socialism to capitalism" (Whiting, 2001, pp. 1-3).

From 1990 to 2000, renewable energy was promoted and use of renewable energy significantly grew, thanks to favorable policies and financial incentives. Rural energy enterprises grew in areas such as biogas digesters, solar water heaters, and PV. The service sector also grew, including areas like service technicians, marketing, and sales. In 1980, rural China's energy consumption was 34 percent fuelwood, 35 percent straw, 5 percent oil, 6 percent electricity and 20 percent coal. By 1998, those values had changed to 15 percent fuelwood, 18 percent straw, 7 percent oil, 15 percent electricity, and 45 percent coal (Luo, 2004) .

Other challenges facing rural China besides energy use include access to health care, education, environmental pollution and protections, and more recently, migration away from rural areas. Some authors argue that in earlier studies, the peasant workers of China have been

[6] However, this same paper notes that these mines have poor safety records and indoor air pollution from coal combustion has been shown to be a cause of lung cancer in a county in Yunnan Province.

ignored while researchers focus on the elite, although the reason for this lies in part with researchers' lack of access to China before the 1980's (Fan, Heberer, & Taubman, 2006, p. 3). However, there now seems to be a great deal of work focusing on rural China, and more recently, on the challenges facing migrant workers areas such as health and education (see below for a more in-depth review of migration).

While in 2002 one researcher stated that: "Rural China faces problems for which no quick solutions are evident on the horizon" (Unger, 2002, p. 228), another more recent work explains how people in rural China are depending on themselves, and states that "Factors such as urbanization, the marginalization of social groups, the emergence and influence of the business elites, and the potential for dissent by Internet users, present interesting challenges and insights into the working between state and society. The cumbersome state has meant social actors, such as entrepreneurs and migrant workers, are increasingly relying on themselves, rather than waiting for solutions dictated by the government. Nonetheless, the state is still dominant and far from retreating from the social realm – it is presently reconfiguring itself to better "manage society". What we see is the beginning of an era of transition where the Chinese state no longer has a monopoly on managing social development". (Hasmath & Hsu, 2009).

China frequently uses slogans, and the development arena is no stranger to them. Development slogans employed in the recent past have included: "The great development of west China", "Coordinating urban and rural development and coordinating regional development" and "The construction of a new Socialist rural China" (Zhou, Wu, Chen, & Chen, 2008, p. 2228). These slogans show the push to develop more remote, western areas of the country and promote rural development.

2.1.2.1 Rural Energy Issues

Researchers have found that found that home appliances increased with income, particularly at higher income levels, and also that as income increases, people switch to cleaner fuels.

> "Over recent decades, many studies have observed that the process of economic development is generally accompanied by a shift within developing country households toward increasing use of modern fuels and decreasing reliance on biomass, even in the absence of policies explicitly aimed at achieving this outcome. Understanding this 'energy transition', as it has come to be called, is therefore of prime importance for designing policy interventions" (Jiang & O'Neill, 2004, pp. 3, 16).

One persistent development challenge in rural energy is that of on-going maintenance, as seen in challenges implementing solar electric systems. A 'low awareness of renewable energy technology' points to a need for renewable energy education. Training and standards are also important to ensure the quality of such systems. Installing electricity is not enough to insure people's economic situations; other key factors such as access to markets must be in place. Additionally, community participation and integration help address wider development planning among others (To, 2007).

The issue of management training to build capacity in organizations responsible for new power systems at the village level is mentioned in another paper, along with the importance of designing electrical systems to meet future predicted (and not just current) loads. Another key issue is who pays for these systems. Rural electric systems can also be used to create income and develop living conditions (Wallace, Wu, & Wang).

Use of improved stoves can also be seen as a way to help prevent deforestation – improved stoves, biogas, and other technologies can help with air pollution, water pollution and forest resources. Understanding fuel demand and adoption of new technologies is a key step in protecting the environment and people's health. However, different regions of China have different cultures and needs, and these definitely need to be taken into account. A 'one size fits all' mentality for the entire country is simply not appropriate (Chen, Heerink, & van den Berg, 2006). Indeed, Chinese people themselves recognize differences, especially between North and South China and many Chinese people are identified as either being from the North or South in introductions to others (Guo R. , 2009, p. 25).

One challenge in implementing new cooking methods is the difference between laboratory testing and real-life situations. Just because a stove or fuel source has reached high efficiencies in the lab, it may not be able to actually achieve those results in the field (Smith & Zhang, Household air pollution from coal and biomass fuels in China: measurements, health impacts and interventions, 2007).

Biomass has at various times been promoted as a 'sustainable' fuel source, and may involve creating value from waste products such as rice husks or sawdust (Amaya, Medero, Tancredi, Silva, & Deiana, 2007, p. 1635). The main household energy sources for rural Northern China are straw, firewood, and coal, and consumption of these did not change much between 1996 and 2005, staying at about 90 percent of total rural household energy consumption (Zhou, Wu, Chen, & Chen, 2008).

2.1.2.2 Poverty in China

Another challenge facing rural China is the debate about what the poverty line actually should be. Some researchers state that the original rural poverty line "does not adequately reflect the needs of rural residents to develop their own capabilities (principally with respect to health care, education, etc.)" and present a new poverty line concept (Xiaolu, Shi, & Sangui, 2009).

Suggestions for poverty alleviation policies presented by the China Development Research Foundation are to:

> "establish a development poverty line and adjust long-term poverty alleviation objectives; establish a reasonable credit mechanism for poverty alleviation and define the financial sector's participation; establish and completely implement the social security system for rural and urban areas; support the drive for urbanization and provide social security and public services to migrants from rural areas working in urban areas; provide fairer educational opportunities; provide more intensive training to rural labourers on employment, occupational skills and labour transfers; improve rural medical services; establish a reasonable public finance-assisted poverty alleviation mechanism and reinforce government oversight; and expand the role played by non-governmental organizations in poverty alleviation" (Xiaolu, Shi, & Sangui, 2009, pp. 218-229).

The urban-rural income gap is another important component of poverty within China. While much research has been done on the urban-rural income gap in China, and it is generally accepted that there is a large gap between urban residents' and rural residents' incomes, some researchers feel that estimates for the size of this gap may be too large. Issues that may lead to this over-estimation are missing components of income data (such as housing-related income and consumption of public services), spatial differences in the cost of living, and use of data that does not account for unregistered migrant workers. Accounting for these differences does significantly lessen the urban-rural income gap from previous estimates, but it still remains substantial. Researchers found that the urban-rural income gap is much greater in western China, and suggest targeting the west when focusing on this issue (Sicular, Ximing, Gustafsson, & Li, 2008, pp. 30-31, 62-63).

Researchers explain that it is important to take migrant workers into account when assessing the urban-rural income gap. Since migration is seen as one way to decrease this gap, it would be foolish to leave out migrant workers in the assessment. Migrant workers usually have incomes greater than rural residents and less than registered urban residents. Additionally, inequality measurements in other countries generally include migrants (Sicular, Ximing, Gustafsson, & Li, 2008, p. 31).

2.1.2.3 Environmental Justice

Poor people across the globe may be at greater risks for environmental injustices, and can have serious health consequences from lack of access to clean water and sanitation, clean energy, and clean air. Other issues facing people in poverty can be proximity to dangerous factories such as chemical plants, and lead poisoning from vehicles, which can have devastating effects on children's development. The idea of exporting waste to less developed countries has also been prevalent (Bullard, Johnson, & Torres, 2005, pp. 279-287). Indeed, within China, different people definitely face an "uneven distribution of environmental risks" (Tilt, The Struggle for Sustainability in Rural China: Environmental Values and Civil Society, 2010, pp. 8-9).

According to one researcher, "China's rapidly deteriorating environment is not merely a material problem but a sociopolitical problem as well". Therefore, moving forward to take better care of the environment will require public awareness and "public support for changing course"

(Tilt, The Struggle for Sustainability in Rural China: Environmental Values and Civil Society, 2010, pp. 8-9, 83).

2.2.2.4 Moving Forward

What is the best way to move forward in implementing clean energy solutions for China in general and rural China specifically? In a *Wall Street Journal* report on energy, the authors argue that nations should focus on decreasing the cost of clean energy, rather than raising the price of fossil fuels. They offer new approaches for moving forward, including investing in lowering the cost of clean-energy technologies, focusing on modest emissions reductions, and creating an agreement between the 20 largest world economies. They also argue that development aid should be provided to communities in need, regardless of whether it is 'climate-related aid' or not. As they explain, rather than trying to determine if natural disasters are related to climate change, rich nations should provide aid for problems connected with disasters, as well as help develop infrastructure such as roads, water, and sewage systems so that countries are better prepared for disasters when they come (Nordhaus & Shellenberger, 2010).

2.2 Social Issues in China

2.2.1 Migration

Encompassing many of the issues described above, migration is one of the key issues facing China today (McKinsey and Company), (Seligsohn, 2010). A brief review of topics covered in migration-related research finds research in a number of areas, including migration and education, issues related to the *hukou*, social security, women and community, mental health, children of migrants (including education, parent absence and resilience of children left behind), labor shortages, HIV/AIDS issues, sexual trafficking, housing, and cell phones[7].

Research focused on migrant workers in Beijing includes research on the *hukou*, migrant children's education, law enforcement campaigns, unemployment, access to civil justice, migrant construction teams, health-related topics (including maternal mortality rate, HIV/AIDS, and measles), migrant women, housing choice, and again, mobile phones[8].

Several excellent books focus on in-depth studies of specific migrant communities (Biao, 2005), (Zhang L. , Strangers in the City: Reconfigurations of Space, Power, and Social Networks Within China's Floating Population., 2001). These books take a sociological and anthropological approach to understanding the lives of migrant workers.

According to Leslie Chang, author of Factory Girls, young Chinese migrants are the 'rural elite', coming from the schools, not from the farms. They leave behind older family members to work the land, and send money back. Migrants leave not just for financial opportunities, but also because they may be bored at home. They are bravely seeking new adventures and often have a plan for where to work when they leave (Chang L. T., 2008, pp. 11-13). As Chang explains: "Migrant workers use a simple term for the move that defines their lives: *chuqu*, to go out. *There was nothing to do at home, so I went out*. This is how a migrant story begins" (Chang L. T., 2008, p. 11).

Qian Cai also sees migrants as gaining skills and experience along with income (Cai, 2003). Other authors see migrant workers as marginalized, discriminated against, and at risk for mental health problems (Wong, Chang, & He, 2007).

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[7]A GoogleScholar search for "allintitle: migrant china" on June 30, 2011 returned 287 responses.
[8]A GoogleScholar search for "allintitle: migrant Beijing" on June 30, 2011 returned 80 responses.

2.2.1.1 Number of Migrant Workers

Estimates of the number of migrants in China vary because this data is difficult to collect for a variety of reasons– one source states there are 150 million migrants in China, with 90 million under 30 (Chang A. , 2011), while another, citing the National Bureau of Statistics, says there were more than 229 million migrant workers as of the end of 2009 (Moxley, 2010).

According to Rachel Beitarie, while China now has more than 400 million internet users, there are another billion people who are waiting to be integrated into the economic improvements of China as a whole (Beitarie). One difference between the younger migrants and their parents' generation may be that they plan to stay in the cities, while their parents may have hoped to earn money and then return home to their farms. These young people no longer know how to farm, and likely feel more at home in the city than the countryside (Chang A. , 2011). Migration also has a seasonal component, as workers may return home for several weeks during Spring Festival, and some return home during the summer to help with the harvest (Guo R. , 2009, p. 225).

2.2.1.2 Urban Poverty

The recent global economic downturn resulted in millions of Chinese migrant workers losing their jobs, and 'might even mean the end of China's current model of export-oriented accumulation' (Wu, Webster, He, & Liu, 2010). Recently the Chinese government has used different terms for poor households, including *"di shouru qunti* (low-income groups), *ruoshi qunti* (weak social and economic groups), and *chengshi pinkun jumin* (urban poor residents)" (Wu, Webster, He, & Liu, 2010, p. 5). Poor university students are viewed as urban poor, since they have the chance to register as urban residents after they graduate (Wu, Webster, He, & Liu, 2010, p. 5).

Migrants may actually be able to survive urban poverty better than urban residents, since they are willing to take lower-profile jobs, however, they face competition for those jobs from other migrant workers and often are paid very low wages (Wu, Webster, He, & Liu, 2010, p. 77).

2.2.1.3 Idea of C*hengzhongcun (城中村)*

This idea of a village within a city is also explained by Li Zhang. According to Zhang, *chengzhongcun*, which means 'a village within the city' are areas that are classified as rural areas, but are close to the edge of the city and become 'swallowed up by urban expansion'. In these areas, migrant workers may outnumber city residents. While these communities provide migrant workers with an important support (and low rent), they may be viewed with distaste by city officials who wish to impose more order and city-like rules on the area (Zhang L. , Contesting urban space: development of chengzhongcun in China's transitional cities, 2009, pp. 103-104)

Chengzhongcun help create migrant workers' social networks and sense of identity as rural people within the city. They also strongly connect to sense of space, and spatial barriers between rural and urban people (Zhang L. , Contesting urban space: development of chengzhongcun in China's transitional cities, 2009, pp. 104-107). Important qualities of a chengzhongcun are low rent, location (close to employment and public transportation), and in some cases, being able to live near people from the same or nearby hometown or province, although this may not be the main situation. These areas also typically provide services specifically for migrants, such as help with renting or moving (Zhang L. , Contesting urban space: development of chengzhongcun in China's transitional cities, 2009).

2.2.1.4 The *Hukou* Issue

It seems impossible to talk about migration in China without talking of politics. Dr. Dorothy Solinger explains that “the emergence of a new urban underclass in China is a major challenge confronting the Communist Party, and its potential for fomenting instability has unnerved the Party” (Solinger, 2006). It seems that the government is concerned about uprising by poor and mistreated people, and it deals with this potential threat in a number of ways: by giving people some venues for pressing their grievances, developing new welfare measures, and by using high-tech surveillance methods and crowd control techniques (Solinger, 2006, p. 177).

Solinger identifies three groups within the cities that give the government concern: unemployed former workers, farmers from the countryside who come to the city for work, and poor people, who are mostly a mix of these two other groups (Solinger, 2006, p. 178). The history of migration begins in the 1950s, when the government tried to keep rural people from living in the cities. After the Great Leap Forward, the government resettled people who had managed to enter the cities back to the farms. Rural people were not allowed into cities until the early 1980’s, however they still were not allowed to switch their *hukou*, so had no access to benefits (Solinger, 2006, pp. 182-183). As Solinger explains in these few quotes:

> “At that point, within just a few years of Chairman Mao’s demise in 1976, there was sudden, headlong industrialization and frantic building in the cities. This, combined with the lack of services that had occurred during the socialist era (socialist China’s urban focus was on heavy industry), carved out a gaping chasm into which peasant workers – freed from the farms as a result of the ending of the communes in 1982 – increasingly poured” (Solinger, 2006, p. 183).

"If the state did not mark these people with the denigrating label of 'peasant registration' (*nongmin hukou*) and were its local officials not intent on attracting outside investment by sustaining access to low-wage, defenceless labour, the treatment afforded these workers could be improved" (Solinger, 2006, p. 183).

"…the temporary use of Chinese labor is institutionally legitimated by the Chinese state, whose *hukou* system, albeit changing, provides population and labor control that favors global and private capital" (Ngai, Made in China: Women Factory Workers in a Global Workplace, 2005, p. 5)

This issue of the *hukou* is highly politically charged. One article cities a study showing that young migrant workers may in fact not want to give up their rural *hukou*, which affords them some benefits, including possible exemptions from tuition and fees, the chance to have more than one child, access to rural medical care, and maintaining land in their hometown. Giving up the *hukou*, while it would provide more benefits in the city, also means they would lose their land at home, which seems to be a sticking point for many young migrants (Moxley, 2010).

"The new *hukou* policy in mega-cities like Beijing and Shanghai is characterized as 'raising the bar and opening the gate'. Those cities have given a green light to intellectuals and professionals seeking to move there but have imposed stricter conditions for ordinary migrant workers. In short, raising the bar means narrowing the door by imposing stricter standards" (Fang & Dewen, 2008, p. 247).

Researchers identify three types of migration – planned *hukou* migrants, permanent migration with or without *hukou* change, and the 'floating' rural labor force (Fang & Dewen, 2008, p. 249).

Migrant workers often face barriers in obtaining higher-paying jobs, and face meager working conditions, low job security, and exclusion from health care, housing, and education for their children. Migrant workers also face deportation from local authorities since they can be seen as a threat and a source of crime within the cities (Fang & Dewen, 2008). Parents have to pay fees for their children to attend the public schools in the city they've moved to (although the government has moved to abolish these fees they are still charged in many cases), and while the private schools have lower fees they often are not of high quality (Wong, Chang, & He, 2007)[9].

> "All these factors prevent migration in China today from being complete and permanent and they result in rural-urban migration having some unique features: migrants have a relatively low standard of living compared to their real incomes, they remain economically and culturally separated from urban society, and migration continues to be an individual rather than a family phenomenon" (Fang & Dewen, 2008, p. 261).

"Spontaneous migrants in China today occupy a special position because they are 'freed' from a territorialised state control system, a system based on rigid divisions between the urban and the rural, and between provinces and cities. Underpinning these boundaries of state regulation is the unique household residency permit or *hukou* system, often seen as the key institutionalised obstacle to spontaneous migration in China" (Biao, 2005, p. iv).

China is expected to join the middle-income countries in 2020. These countries have on average, 23 percent rural population, and China is expected to have a similar rural percentage by

[9] Research on 4th-6th grade migrant and non-migrant students in Beijing found that migrant students did not have necessarily worse performance than non-migrant students in reading and math, but that educational expectations of parents and children were positively connected with math and reading grades (Guo J. , 2007).

that time. In order for this tremendously huge rural-urban shift to occur more smoothly, continued *hukou* system reform is urged (Fang & Dewen, 2008, p. 267).

The *hukou* system was relaxed somewhat in October 2001, and now "20,000 smaller towns and cities across the country can now issue urban *hukou* to migrants provided they can show proof of having a legitimate address and stable source of income at the place of destination" (Biao, 2005, p. x).

2.2.2 Lives of Migrant Workers

2.2.2.1 Eating Bitter

Bryan Tilt, in his excellent study of Futian township in Sichuan Province, speaks of migrant workers' willingness to 'chi ku' or eat bitter – working long hours, sometimes seven days a week, 12 hours a day, to provide financially, and explains: "…as migrant laborers, factory workers lacked access to local agricultural land and thus had no economic safety net. Their only chance for success in China's highly unpredictable economy depended on just this sort of self-sacrificing behavior". (Tilt, The Struggle for Sustainability in Rural China: Environmental Values and Civil Society, 2010, pp. 104-105). However, younger migrants may not be able to eat bitter the same way their parents have (Chang A. , 2011, p. 2).

Migrant workers in Beijing often have a desperately hard life. A vast number of migrant workers (some estimates are up to a million people) live in the old air-defense tunnels under the city of Beijing. These people are known as the "mouse tribe" and provide services to the people living above them (Wong E. , 2011).

Factory workers, for example in southern Chinese factories in areas such as Guangdong and surrounding provinces, work long hours and are frequently exhausted. Since the turnover rate is high, workers are trained to do only one job, so they can be easily replaced if and when they leave (Ngai, Made in China: Women Factory Workers in a Global Workplace, 2005).

As of 2000, provinces that migrant workers left *from* the most were Sichuan, Henan, Anhui, Hunan and Jiangxi. Areas workers most migrated *to* were Beijing, Shanghai, Guangdong, Zhejiang, and Fujian (Wong, Chang, & He, 2007).

Migrant workers suffer in many different ways: withholding of wages, poor working conditions, no social security or medical benefits in the cities they migrate to, and high educational expenses for their children. Additional challenges are lack of access to decent housing and discrimination by city residents. All of this suffering is expected to have a psychological impact on migrants, and studies have shown mental-health symptoms such as anxiety and difficulty falling asleep (Wong, Chang, & He, 2007).

Rachel Murphy explains how urban people often look down on migrants:

> "The attitude of urbanites toward migrants is one of economic acceptance coupled with social rejection. Rural migrants are described by municipal authorities as wailai renkou (meaning "outside population") rather than yimin (which means "migrant"), emphasizing that these people are transients. Members of the wailai renkou are like migrant workers the world over, confined to arduous, dirty, and dangerous jobs" (Murphy, 2002, pp. 42-43).

These jobs have also been called the "3-D" jobs – dirty, dangerous, and difficult (Ping & Shaohua, 2008, p. 233), (Cai, 2003). Migrant workers can be viewed by city residents as being connected to crime increases within the cities, responsible for taking jobs that should go to urban residents, ignorant, and 'a threat to social stability' (Wong, Chang, & He, 2007).

2.2.2.2 Female Workers (打工妹)

Female migrant workers often face especially difficult challenges as they leave home. Pun Ngai, in her ethnographic study of factory life in Shenzhen, China, speaks to issues facing women migrant workers, or dagongwei (打工妹) (also could be pronounced dagongmei). These three Chinese characters represent fight, work, and sister on their own, respectively. Some rural women are expected to work outside the home before they are married, but then expected to return to the village to be married and raise their families as the following quote discusses.

> "Quitting work for marriage and then returning to village life is still the shared feature of most migrant working daughters, although this common fate is not without resistance" (Ngai, Made in China: Women Factory Workers in a Global Workplace, 2005, pp. 5-6).

In Pun Ngai's book, one migrant female worker talks of wanting to see the outside world, and thinking they were *jing di zhi wa* (井底之蛙) which is translated by Pun Ngai as 'frogs living in a well, knowing nothing about the outside world' (Ngai, Made in China: Women Factory Workers in a Global Workplace, 2005, pp. 66-67).

> "The stories of migrant women shared certain features. The arrival in the city was blurred and confused and often involved being tricked in some way. Young women often said they had gone out alone, though in fact they usually traveled with others; they just felt alone. They quickly forgot the names of factories, but certain dates were branded in their minds, like the day they left home or quit a bad factory forever. What a factory actually made was never important; what mattered was the hardship or opportunity that came with working there… It

was easy to lose yourself in the factory, where there were hundreds of girls with identical backgrounds: born in the village, badly educated, and poor. You had to believe that you mattered even though you were one among millions" (Chang L. T., 2008, p. 55).

The challenges of leaving a factory and starting over are also explained by Leslie Chang:

"The girls talked constantly of leaving. Workers were required to stay six months, and even then permission to quit was not always granted. The factory held the first two months of every worker's pay; leaving without approval meant losing that money and starting all over somewhere else. Getting into a factory was easy. The hard part was getting out" (Chang L. T., 2008, p. 4).

2.2.2.3 Remittances

Other researchers seek to determine the effectiveness of remittances (money that workers send home to their families) on rural development, and look at the contrast of how remittances may improve quality of life for rural residents, while the family members sending them suffer in poverty in the cities. Benefits of remittances may include narrowing the rural-urban income gap, reducing rural poverty, paying for basic education and health care, and promoting consumption and investment. (Ping & Shaohua, 2008).

Asking people to self-report income can be challenging, since respondents may inaccurately report their income, and may have difficulty relating which part of their income comes from remittances. It also can be challenging to assess the overall 'income' of a household before and after migration. However, it has been found that "migration broadly correlates with better standards of living for the participating households" (Murphy, 2002, pp. 53-54).

Remittances may be used for living expenses, educational fees, and medical expenses, among other costs (Ping & Shaohua, 2008, p. 223). While remittances usually do not go toward farming, occasionally they are used to improve the ability of a family to use their land productively (Murphy, 2002, p. 81).

One study on remittances using survey data showed that while education had no effect on remittances, male gender, level of income, temporary migration status and family ties did have a positive effect, with family ties being the most significant factor. Migrant workers who brought money from home, received money from home, or visited home (at least once in the year leading up to the survey) were much more likely to send remittances home (Cai, 2003).

Remittances can reflect family relationships, and sending them can be seen either as motivated by altruism or self-interest (for example if a migrant has a child or farmland back at home, or wants to maintain ties as insurance against the risk of unemployment). They help migrants stay connected with their home family and maintain social status. A third view sees remittances as a "coinsurance" policy, allowing money to flow both directions as needed (Cai, 2003).

Qian Cai explains that remittances from migration can play a central role in rural development and quotes a saying in China: "One migrant can alleviate one household, and a hundred migrants can solve the poverty problem of a whole village" (Cai, 2003). Migrants may eventually return to their village, for various reasons:

> "Many migrants are compelled to return to their villages because of ill fortune in the cities or family obligations at home. Through migration, these returnees have been exposed to new values and alternative ways of living, causing some of them to form goals that are

incompatible with village life. At the same time, migrants who are forced to return home often lack the resources required to attain their goals and so feel frustrated. But not all of the disruption is detrimental to village society, because the experience of living in the cities gives some returned migrants the impetus to challenge the values and social arrangements of home that they find oppressive" (Murphy, 2002, p. 196).

This relates to this work as this agent-based model attempts to predict at what age migrant workers may move to the city. Future versions of the model could incorporate a calculation for migrant workers returning home, but currently the model assumes workers will remain in the city.

2.2.2.4 The Importance of Community

One issue that may be connected to the health of migrant workers is their sense of community and connectedness with people in their lives. "Being socially connected has been shown to be good for one's health – the chance of dying in a given year, no matter the cause, is two to five times greater for isolated than for socially connected people" (Gardner, 2006).

Some researchers found that migrant workers were in fact very well connected with their neighbors, which was not surprising since workers from the same home town often live in close proximity in the city, and workers, who may not have a large social circle, develop friendships with their neighbors (Wu, Webster, He, & Liu, 2010, p. 93).

Indeed, family networks appear to be a significant factor in directing where workers head when they leave their villages.

> "As a consequence of social and cultural gaps between rural and urban areas, as well as serious discrimination in industrial areas, rural migrant workers showed their power and creativity in making and remaking their familial and kin networks in the village" (Ngai, Made in China: Women Factory Workers in a Global Workplace, 2005, p. 56).

Working in the factories, a sense of community and friendship remains essential to survival. Leslie Chang explains this sense of community, along with the ease of losing people: "Girls often quit a factory in groups, finding courage in numbers and pledging to join a new factory together, although that usually turned out to be impossible. The easiest thing in the world was to lose touch with someone" (Chang L. T., 2008, p. 5).

One researcher argues that the business networks developed by migrant workers are in fact beneficial to the cities where they reside. Additionally they feel that greater flexibility in regulations is needed in areas such as managing housing compounds, public safety issues, and economic boundaries. Better interactions between urban society and migrant communities are necessary, rather than just trying to hide such areas behind (literally) high walls. The author concludes that: "spontaneous rural-urban migration can be a critical force for national development, and not a threat to the proper regulation of order" (Biao, 2005, pp. 178-180).

2.2.2.5 Technology for Community

As of April 2011, the number of cell phone users in China reached more than 900 million (Ministry_of_Industry, 2011). This is roughly 67% of the population (population estimated at 1.341 billion by the end of 2010) (Juan, 2011). The importance of cell phones to migrants is discussed by Leslie Chang in her book Factory Girls:

"The mobile phone was the first big purchase of most migrants. Without a phone, it was virtually impossible to keep up with friends or find a new job. Letters between factories often went missing, and calling up a worker in her dorm, where a hundred people might share a hallway phone, was difficult. …people jumped jobs so often that dorm and office numbers quickly went out of date. In a universe of perpetual motion, the mobile phone was magnetic north, the thing that fixed a person in place" (Chang L. T., 2008, p. 95).

The importance of the mobile phone in a migrant worker's life is further explained by other researchers as well. Chu and Yang feel that it's important to understand how cultural impacts cell phone use, and feel that "there is particular cultural meaning in the use of a cell phone to peasant workers who have their own unique background" (Chu & Yang, 2008, pp. 222-223). The study of cell phones brings up fascinating questions of connection, social status, accessibility, community and belonging. As Chu and Yang explain:

"…by celebrating its ability to sustain a perpetual contact, one may easily overlook the very fact that using a cell phone is also a way to hide from a time-space to which one does not feel much of a sense of belonging". Migrant workers may spend three to four months of their monthly income on cell phones (Chu & Yang, 2008, p. 225).

Cell phones have an important connection to the sense of feeling empowered, and controlling technology may help these young people 'rebuild their self-esteem'. For these migrant workers, "in a place where they have been marginalized and into which they have very little hope of becoming anchored in the long run, to get a taste of manipulating technology at ones' discretion is an extremely meaningful experience" (Chu & Yang, 2008, pp. 229, 234).

Younger migrant workers seem to differ from their parents' generation in that they are more prepared, especially by watching television, for life in the city, and more discontent with the difficulties of peasant life. However, since they cannot become true city residents, this sets them up for much greater frustrations, since they do not want to return home to the countryside, yet do not truly belong in the city. Cell phones seem to serve as a means of empowerment, enabling them to connect with their families back home, and send SMS messages to friends and lovers silently from the privacy of their factory dormitory bunk. SMS messages also relate back to the important Chinese cultural concept of reciprocity within a relationship. Returning someone's 'grooming message' of care may help to build and maintain important social bonds within a sub-culture of people who are displaced from their homes. Cell phones are also an important status symbol. Having one, having a color (rather than just black or white one), or having a newer model are all important social metrics (Chu & Yang, 2008).

Cell phones and SMS messages play a role in helping young migrant workers navigate romantic relationships. Workers from more traditional backgrounds may feel awkward talking in person with a romantic interest of the opposite sex, and may be more comfortable interacting via SMS message, or in some cases, online networks which can lead to romantic encounters (Law & Peng, 2006).

2.3 Mathematical Modeling of Energy Use in China

Predicting energy demand and consumption is extremely complicated. China is still categorized as a developing nation but has seen very high economic growth rates over the past few years, so predicting China's energy demands and corresponding emissions is a challenging task.

Work on modeling energy use in China ranges from research on a model of energy consumption at the household level for rural villages (Chen, Heerink, & van den Berg, 2006), and energy supply and demand at the village level (Zhen, A model of the energy-supply and demand system at the village level, 1993), to predicting future carbon dioxide emissions for the entire country (Auffhammer & Carson, 2007).

Researchers have employed different types of mathematical models in their attempts to model energy use and predicted emissions, whether at the local or country-wide level. Back in 1993, one older paper uses a network diagram to model actual energy flow and then a system dynamics model to predict village-level energy supply and demand (Zhen, A model of the energy-supply and demand system at the village level, 1993). This same author, from the China Center for Rural Technology Development, also developed a multiple-linear programming model to examine factors of energy, economy, and ecology for the planning of rural energy systems (Zhen, An MPL Model Applicable to Rural Energy System).

Jumping forward 17 years to 2000, a group at Harvard's Kennedy School was also looking at the factors of the economy, energy, and the environment. They developed a dynamic economy-energy-environment model of China, which includes environmental factors such as particulate and sulphur dioxide pollution, as well as economic factors in an attempt to predict growth, energy use and pollution (Garbaccio, Ho, & Jorgenson, 2000). Additional work looking at the energy-economy connection has used CIMS, a hybrid energy-economy model, to see how various policies could affect China's environment and economy. The authors found that different modeling techniques produced significantly different results on cost estimates of greenhouse gas emissions (Tu, Jaccard, & Nyboer, 2007)

Human behavior is also a key element of predicting and evaluating energy use - whether assessing household energy savings and consumer behavior (Feng, Sovacool, & Vu, 2010), or improving occupants' behaviors in a residential sector (Ouyang & Hokao, 2009). China's energy consumption is also dependent on temporal and spatial variations (Zhang, Yang, Chen, Chen, & Zhang, 2009).

A group at Tsinghua University in 2007 developed a literature survey of energy models used for China that gives a useful overview. The paper suggests holding an energy modeling forum in China for modelers and policy makers, and states that models currently used for China do not adequately take into account some of the particular issues facing a developing country. The paper gives a summary of both bottom-up and top-down models, and covers MARKAL, LEAP, AIM and 3E in more depth. Conclusions of the study were that China has developed several of its own models, (by Chinese developers for use in China) and some key factors of developing countries are not included in current models. Additionally, the authors feel that comparison between models is not feasible, as reference scenarios and policy scenarios in different models are quite different. Lastly, the authors state that "there is no wrong model, only the wrong application," as different models can be best applied to different problems or questions (Tang, Gu, & Duan, 2007).

A review of multi-criteria decision making (MCDM) techniques in 2004 found that Analytical Hierarchy Process was the most used method, followed by PROMETHEE and then ELECTRE (Pohekar & Ramachandran, 2004).

In their modeling work, Jiang and O'Neill found that household expenditure is the highest predictor of per capita total energy use, followed by location and yearly temperatures. They also found that commercial energy use increases with income (Jiang & O'Neill, 2004, pp. 22-23).

A recent paper estimates future carbon emissions for rural and urban China by predicting population flow and energy consumption using the China Statistical Yearbooks and a modified version of the gravity model of transfer of population (Hong, Pengyuan, & Wei, 2011)

One mathematical model was able to predict China overcoming the United States in carbon dioxide emissions in 2010, rather than in 2020 as predicted by other researchers. However, both groups were ultimately wrong, as China surpassed the United States in CO_2 emissions in 2008 (Auffhammer & Carson, 2007, p. 1). Auffhammer and Carson, in predicting carbon dioxide emissions for China, found that dynamic models with spatial dependence were superior to the static environmental Kuznets curve, which has pollution rising with income and then falling after some point (an inverted U-curve). They feel that since China is responsible for such a large percentage of the world's emissions, accurate forecasting is essential. For their model, they used spatial and time series variation, chose the "best" model from a large class of models, allowed for 'spatial dependence in emissions across provinces', and used 'annually updated and publically available' data from the Chinese government. In 2007, they found that other models seriously under-predicted CO_2 emissions, and stated that 'the magnitude of the projected increase in Chinese emissions out to 2015 is several times larger than the reductions embodied in the Kyoto Protocol,' which clearly has political and environmental ramifications (Auffhammer & Carson, 2007).

According to Auffhammer and Carson, there are three branches of carbon dioxide emissions literature. The first, citing Eldrich and Holdren (Ehrlich & Holdren, 1971) involves thinking of carbon dioxide emissions via the IPAT identity:

$$I = P \times A \times T$$

where I is impact ('typically measured in terms of the emission level of a pollutant'), P is population size, A is affluence of a society, and T 'represents a technology index'. Emissions are expected to 'monotonically' increase with population and affluence and decrease with technology improvements. The second branch also uses the IPAT model along with economic tools such as the Kutznets curve, to 'estimate reduced form models,' although there are contradictions between the down-slope of the Kutznets curve and the linearity of the IPAT model. The third branch uses input-output tables from sector-level data to create computable general equilibrium (CGE) models. These models need a lot of data and are good for policy applications, but can't be used for forecasting since they cannot be calibrated. Additionally, data may be provided rather infrequently. Citing Zhang (Zhang Z. , 2000) they also explain that the primary cause of increasing emissions is increasing income (Auffhammer & Carson, 2007).

2.3.1 Agent-based Modeling

There are several key categories of models: agent-based models (AMB), equation-based models (EMB), social network models, deterministic models, stochastic models, and Monte Carlo simulation models (Cooley & Solano, Agent-based model (ABM) validation considerations, 2011). Agent-based modeling (ABM) is a specific type of modeling that is especially good for modeling human behavior. Application of agent-based modeling to this work is covered in depth in the model methods and results section (Chapter 5). An overview of agent-based modeling including uses, limitations, and validation follows below, with more details explained in Chapter 5. An excellent overview paper on agent-based modeling is available in the literature as well (Macal & North, 2010).

2.3.1.1 Uses of Agent-based Modeling

Agent-based models have been used for a wide variety of applications ranging from physics, biology, chemistry and the social sciences. In reference to NetLogo models in particular, one researcher explains:

> "Model application areas range from biology to computer science to art to artificial life and include simulations such as predator-prey, spread of disease, rumor mill, traffic jams, small worlds, fractals, erosion, dining philosophers, cellular automata, crystallization, and radioactivity" (Skylar, 2007, p. 303).

A good explanation of the range of possible applications is provided in the following excerpts by Macy and Willer:

> "... ABM's are used to perform virtual experiments that test macrosociological theories by manipulating structural factors like network topology, social stratification, or spatial mobility" (Macy & Willer, 2002, p. 143).

The authors also explain:

"These agent-based models (ABMs) show how simple and predictable local interactions can generate familiar but enigmatic global patterns, such as the diffusion of information, emergence of norms, coordination of conventions, or participation in collective action. Emergent social patterns can also appear unexpectedly and then just as dramatically transform or disappear, as happens in revolutions, market crashes, fads, and feeding frenzies. ABMs provide theoretical leverage where the global patterns of interest are more than the aggregation of individual attributes, but at the same time, the emergent pattern cannot be understood without a bottom up dynamical model of the microfoundations at the relational level" (Macy & Willer, 2002, p. 143).

These quotes show that ABMs can be used for an extremely wide variety of applications that include some aspect of social interactions.

Toolkits are often used for creating agent-based models, and NetLogo is a widely used toolkit. The Net Logo library of models which can be freely accessed via their website and used as a jumping-off point for research or development of a new model includes more than 100 models in fields as wide ranging as the following (Net Logo):

- Biology
- Chemistry
- Physics
- Computer science
- Earth science
- Mathematics
- Social science
- System dynamics

One specific example of application in the biology field is a model to simulate the spread of HIV. This model gives the user control (via sliders) over a number of input factors, such as number of initial people, average coupling tendency, average length of commitment, , and average test frequency. This allows the evaluation of many different human behavior related input combinations (Wilensky, NetLogo AIDS model, 1997). Another example is a physics model developed to show the transition from laminar to turbulent flow. This model allows the user to look at interactions between viscosity, turbulence and laminarity (Wilensky, NetLogo Turbulence model., 2003).

A good explanation of how ABMs can be elegantly used to simply explain complex systems is the model of migrating birds in flight. Actions of the birds as individual actors can be simply explained with just three rules: separation, alignment, and cohesion. That is - don't get too close to any object or other birds, "try to match speed and direction of nearby" birds, and move towards the "perceived center of mass" of birds in your nearby area (Macy & Willer, 2002, p. 144).

Dr. Elizabeth Skylar of Brooklyn College, City University of New York, highly recommends use of NetLogo in her review paper for Artificial Life:

"This reviewer, who has used NetLogo for both research and teaching at several levels, highly recommends it for instructors from elementary school to graduate school and for researchers from a wide range of fields (Skylar, 2007).

She also explains:

"Despite the entry-level programming interface, NetLogo is capable of quite sophisticated modeling and allows experienced programmers to add their own Java extensions. As a result, NetLogo has been widely used by a broad audience, from elementary school children to academics in the social, computer, and ‘‘hard’’ sciences; and the online community page includes models constructed by a wide range of representatives from each of these segments of the population” (Skylar, 2007, p. 303).

Agent-based models have four key assumptions as also explained by Macy and Willer:

1. “Agents are autonomous
2. Agents are interdependent
3. Agents follow simple rules
4. Agents are adaptive and backward-looking” (Macy & Willer, 2002, p. 146)

A key aspect of agent-based models is that the agents behave differently under different settings (or, the rules that they are following can change under different settings).

“The most fundamental properties of any agent are that it is autonomous and selfinterested. The agent is equipped with a high-level set of goals; and every time it has a choice of action, it chooses the action that it believes is the one that best achieves one of its goals (or subgoals). This implies the agent has some internal set of rules guiding its decisionmaking and cannot be directly told what to do by another agent; if one agent wishes to change the behavior of another agent, it can only do so indirectly, by effecting some action that alters the best way for the second agent to achieve its own goals. Due to the autonomy of the individual agents, multi-agent systems provide a natural means of structuring simulations of systems where there are multiple loci of control” (Skylar, 2007, p. 304).

Agent-based models differ from other types of modeling but can be used in combination with them, and can be used for policy decisions:

"The flexibility of the ABM approach suits our goal of building models at a level of detail and complexity appropriate to the questions we want to ask in each particular study. In general our goal is not to create models that generate the specific details of particular histories, but instead to create models that help us understand the social processes that lead to the patterns and dynamics common to a variety of situations. While ABMs do not have the formal simplicity of more abstract models (e.g., those based on physical systems), they do allow us to build models that can be more easily related to and used for policy decisions" (Rand, Brown, Page, Riolo, Fernandez, & Zellner).

Agent-based models do not appear to have yet been used (other than this study) to look at migrant workers in China, but have been used to examine migration flows for Burkina Faso, interurban migration in the Twin Cities of St. Paul and Minneapolis, and rural-urban migration by Brazilian researchers (Kniveton, Smith, & Wood, 2011), (Sun & Manson, 2010) (Espindola, Silveira, & Penna, 2006).

2.3.1.2 Limitations of Agent-based Modeling

Probably the greatest limitation of agent-based modeling is that ABMs can be incredibly complex and difficult to model. Agent-based models are created differently than equation based models, or EBMs:

"The difference in representational focus between ABM and EBM has consequences for how models are modularized. EBM's represent the system as a set of equations that relate observables to one another. The basic unit of the model, the equation, typically relates observables whose values are affected by the actions of multiple individuals, so the natural modularization often crosses boundaries among individuals. ABM's represent the internal behavior of each individual. One agent's behavior may depend on observables generated by other individuals, but does not directly access the representation of those individuals' behaviors, so the natural modularization follows boundaries among individuals" (Van Dyke Parunak, Savit, & Riolo, 1998, p. 11).

Additional limitations can include the need to make many modeling decisions about small details and interactions, the fact that different micro models may lead to similar macro results, and that it's often easier to obtain macro (rather than micro) data (Shalizi, 2012). Another significant limitation of ABMs is the difficulty in validating them, as explained in section 2.3.1.4 below.

2.3.1.3 Use of the Logit Function and ABM Performance

Use of the logit function for agent-based modeling has been done by other researchers, including researchers in the field of agent-based (computational) economics (ACE) (Chen, Chang, & Du, 2009). Biomedical engineering research has also made use of the logit function within NetLogo to examine circulating inflammatory cell trafficking (Bailey, Thorne, & Peirce, 2007). Generalized linear models with a logit link function (GLM-logit) were also used in NetLogo to examine the persistence probability *P(persist)* of a population in a study of representations of landscape heterogeneity (Stoddard, 2010).

Agent-based model performance is quite difficult to quantify, based on challenges with validating models, as explained below.

2.3.1.4 Validation of Agent-based Modeling

According to Dr. Michael Lees: "Validation is still a significant problem for agent-based modelers and while various validation methodologies have been proposed, none have been widely adopted" (Lees, 2012). Other researchers phrase it this way: "Validation of agent-based models (ABMs) of land-use change is a significant challenge in current spatial-modelling research and application" (Kocabas & Dragicevic, 2009). Yet another paper states: "Validation of models is a difficult issue and probably one of the most important ones facing the agent based modeling community. A renewed effort to explore and confront these issues is necessary" (Rand, Brown, Page, Riolo, Fernandez, & Zellner).

Agent-based models (ABM) differ from equation-based models (EBMs) in several significant ways, and thus are validated in different ways. According to other researchers:

> "ABM's offer an additional level of validation. Both ABM's and EBM's can be validated at the system level, by comparing model output with real system behavior. In addition, ABM's can be validated at the individual level, since the behaviors encoded for each agent can be compared with local observations on the actual behavior of the domain individuals. (A balancing consideration is that the code needed to represent an agent's behavior in ABM is often longer and more complex than a typical equation in an EBM, and thus potentially more susceptible to representational error.)" (Van Dyke Parunak, Savit, & Riolo, 1998).

Different approaches to validating an agent-based model can be pursued. One paper uses vector-based geographic information system and Bayesian networks to validate a model of land-use change with good results (Kocabas & Dragicevic, 2009).

In spatial models ("complex systems models applied to geographical contexts"), there are generally three approaches to model validation. One view is that such models cannot be validated; the second is that "pattern evolution has to be examined in the validation process" (because results of an agent-based model are so sensitive to inputs); the third is that validation is possible but certain methods must be followed. The authors, while explaining some validation methods that can be used with spatial land-use models, nonetheless conclude that validation is extremely challenging. They then go on to explain implementation of the Bayesian network method (Kocabas & Dragicevic, 2009).

A paper on validation considerations for agent-based modeling gives six specific tests that can be used. The authors also cover various definitions of validation as developed by other researchers: "a satisfactory range of accuracy", "demonstrating the "correct" equations have been solved", and evaluating how well the model depicts the actual world (Cooley & Solano, Agent-based model (ABM) validation considerations, 2011). Another definition gives three types of validity – replicative, predictive, or structural (Ziegler, 1985), (Cooley & Solano, Agent-based model (ABM) validation considerations, 2011).

Validation of a model requires three steps: verification, validation, and sensitivity analysis. Verification ensures that the model is accurate (for example, looks for programming errors), Validation checks against outside information, and sensitivity analysis sees how the model responds to differing assumptions. An overview of key issues for each of these steps follows – summarized from Cooley and Solano 2011 (Cooley & Solano, Agent-based model (ABM) validation considerations, 2011).

Verification: Model verification consists of “the process of checking that a program does what it was planned to do”. One way to do this is by running test cases of “extreme situations in which the outcomes are easily predicted”.

Validation: The goal of validation is to “attempt to demonstrate whether the simulation is a good model of the target phenomena”. However, there are several challenges connected with validation. Because the process being modeled is stochastic, the outputs may not match exactly what might be expected; in path-dependent simulations “early random number choices can greatly influence outcomes”; additionally, “a model may be correct but the target data available for validation is either incorrect or not known”.

Sensitivity analysis: This aspect of modeling “investigates how projected performance varies along with changes in the key assumptions on which the projections are based”. The way to do this is to vary model inputs and see how the outcomes are affected. Because there may be so many different possible combinations of inputs, this can be a strenuous process. A method to decrease the number of combinations needed is to use “randomization of parameters to obtain a sample of conditions”. Distributions or means with confidence intervals can be used to convey results (Cooley & Solano, Agent-based model (ABM) validation considerations, 2011).

Cooley and Solano remind readers that “A model is usually developed to examine a specific set of issues; therefore, model validity should be examined with respect to them”. They state as well that:

“Model components can be validated with historical data. Subject area experts can examine the face validity of the predictions to confirm the similarity of model output to their perceptions of how the modeled events should have developed and progressed. Modelers should examine their results to test the implications of the core model assumptions. If possible, they should use real data from external sources and compare model results with the external data".

The authors further explain:

"Validation of simulation models based on ABM in general should be judged by fidelity, realism, and resolution. These models should be validated on empirical data, as is commonly done for empirical models. Validation is possible through prediction and retrodiction" (Cooley & Solano, Agent-based model (ABM) validation considerations, 2011).

Five validation tests that can be performed include:

- Theory-model tests (does the model describe "the conceptions in the minds of the modelers"?)
- Model-model tests (connect the model with similar other models)
- Model-phenomena tests (does the model connect with observed phenomena?)
- Theory-model tests (does the model make sense with both theory and phenomena?)
- Global sensitivity tests ("assess model parameter sensitivity") (Cooley & Solano, Agent-based model (ABM) validation considerations, 2011).

2.4. Conclusions and Basis for This Work

This review of the existing literature shows while much work has been done on rural energy, air pollution in China, modeling of energy in China, and migration issues within China, a study looking at the effects of migration on energy use in China appears to have not been conducted before. This work takes into account previous work in examining the disease burden from indoor air pollution from solid fuels, evaluation of socioeconomic factors affecting migrant workers, energy and environment challenges facing China and different approaches to modeling energy and emissions for China and creates a novel approach in creating an agent-based model based on personal survey data.

CHAPTER 3
BEIJING MIGRANT WORKERS SURVEY: METHODS AND RESULTS

3 Beijing Migrant Workers Survey: Methods and Results

The two primary data sources for this dissertation are the novel Beijing Migrant Workers Energy survey, created by the author and conducted in the summer of 2011 in Beijing, and the Tsinghua Rural Energy Survey, conducted in 2006 and 2007 in provinces across China. These two surveys differ in that the Tsinghua survey is much larger, with around 4,000 respondents, while the Beijing survey obtained 191 respondents. The nature of the surveys differ as well; while both included questions on education, income, and fuel use for home heating and cooking, the Tsinghua survey was much longer and included numerous questions on home construction, heating equipment, cooking equipment, as well as extra questions on water and sanitation. The novel Beijing survey was much shorter and included new questions especially focused on understanding the situation of migrant workers in Beijing, including questions on energy choice factors, why the respondents chose to move to Beijing, why and when they thought they might leave, and a section for them to write and share how they felt about their lives in the city. These two survey sets complement each other well, as the Tsinghua data gives a robust picture of life in rural China, while the Beijing survey explores some of the opportunities and challenges facing migrant workers, who have often indeed come from rural China to one of their nation’s largest cities.

The major aims of this chapter are to present the Beijing Migrant Workers Energy Survey methods and results. Chapter 4 then gives an overview of the Tsinghua Rural Energy Survey and results.

3.1 Beijing Migrant Workers Energy Survey: Overview

The primary purpose of this survey was to obtain data on migrant workers' use of solid fuels and factors that might impact solid fuel use (age, education, income) for the agent-based model. The research goal was to determine what mix of solid and non-solid fuels they are currently using, and how that differs from their fuel mix back home.

Additional goals were to increase understanding of the socioeconomic situation of migrant workers; why they come to Beijing, why they think they might leave, and the challenges they face in the city. Since there are conflicting reports in the literature about migrant workers' desire to have a *hukou*, a specific goal was to establish how these workers felt about the *hukou* system, and see if workers really saw obtaining a *hukou* as a goal for themselves and their family[10].

3.1.1 Participants

The Beijing Migrant Workers Energy Survey was given to 191 migrant workers in different parts of Beijing city. Chosen locations generally were clothing markets, as they were convenient areas to give multiple people the survey at one time. In these markets, a large number of small booths are clustered close together, making it easy to go from booth to booth to pass out surveys and then return to collect completed ones. The goal was to find participants who were over 18, not from Beijing, and without a Beijing hukou. Survey locations and numbers of participants were as follows.

[10] Engagement with people on a personal level is important to me in my work and I resonate with the following quote: "Scholarly treatments of China's environment often quickly devolve into faceless recitations of dismal statistics. In my view, such an important topic, and one germane to the daily lives of so many people, cannot be studied solely from macrolevel analyses or reviews of existing data and literature. Rather, what is required is an in-depth engagement with the people who are at the center of such dramatic social, economic, and environmental changes" (Tilt, The Struggle for Sustainability in Rural China: Environmental Values and Civil Society., 2010, p. 4).

Table 2: Beijing survey locations and number of respondents

Date	Location	Number of Respondents
August 15, 2011	Small shops in the Wudaokou neighborhood of Beijing.	11
August 19, 2011	Huantie area of Beijing (similar to a chengzhongcun).	10
August 29, 2011	Zhongguancun electronics market.	1
August 30, 2011	Hualian shopping mall near the Wudaokou subway station.	36
September 5, 2011	Yashow clothing market, west side of Beijing.	50
September 7, 2011	Small clothing market, Wudaokou neighborhood of Beijing.	19
September 8, 2011	Large Wudaokou clothing market near FuRenJiaYuan apartment complex.	64
Total		191

In addition to written surveys, video interviews were also conducted, asking many of the same questions as were on the written form. These video interviews were designed to be used in a short 5-minute mini documentary film about the current situation of migrant workers and energy use.

3.1.2 Survey Design

The previously conducted energy survey done by the World Bank in Bangladesh was extremely helpful in developing survey questions for China (Asaduzzaman, Barnes, & Khandker, 2009). Helpful advice in survey design was also provided by fellow Fulbright student, Nate Becker and some of the resources he recommended (Becker, 2010), (Lohr). A journal article on good practice for conducting and reporting survey data was also helpful (Kelley, Clark, Brown, & Sitzia, 2003).

Many different factors were involved in the development of the original (2009-2010) versions of the rural energy attitudes survey. The overall goals were to examine rural communities to determine rural adults' knowledge of renewable energy; awareness of the health effects of fuel use (especially coal); priorities in choosing their fuel sources; socioeconomic factors; factual knowledge about renewable energy (both broadly and about specific technologies); perspectives on challenges faced in using energy for cooking, heating, and cooling; attitudes towards socioeconomic representation of using different types of energy; view of the future of rural China and how it can develop and move forward in an energy efficient way.

In 2011, works on both qualitative and quantitative research methods in geography were helpful in thinking about the author's previously conducted research and planning future work (Hay, 2005), (Montello & Sutton, 2006). Discussions with Dr. Emily Yeh and Dr. Tim Oakes, both of the University of Colorado at Boulder, were also helpful (Oakes, 2011), (Yeh, 2011)

Design of 2011 questionnaires was also influenced by Sharon Lohr (Lohr) and her guidelines for writing excellent questionnaires. Based in part by her work, the goal in creating the survey was to ask specific questions that directly answered the questions of interest, while paying attention to clarity and remaining aware of the possible impacts of question order.

The Beijing Migrant Workers Survey was based on previous experience surveying in rural China and Beijing, with additional questions specifically focused on migrant workers added in after doing extensive reading on migration issues for the migration section of the literature review. This process of in-depth reading on issues facing migrant workers enabled the addition of several pertinent questions, including ones on why the respondents came to Beijing, how long they thought they would stay and why they might leave, if their children lived with them or back in their hometown, and very importantly, if they had a Beijing hukou or not, and if they wanted to have one. A unique question of the survey was the last one, which invited the respondents to share about their life in the city. While many people left this question blank, the answers that were received were fascinating and provided an often heartbreaking look into the lives of the migrant workers that were surveyed.

The survey consisted of two sets of questions. The first set covered the basics: age, hometown, number of years in Beijing, education, fuel used for cooking, fuel used for heating, gender, marriage status, children, where the children live, income, spending, amount spent on heating fuel, and amount spent on cooking fuel. The next section included more in-depth questions, most of which were multiple-choice. These questions focused more on why respondents chose to come to Beijing, if they wanted a hukou or not (also if they had one or not), how long they thought they would stay in Beijing, if they knew what renewable energy was, and what they thought China should do about the issue of migration and increased energy usage.

3.1.3 Procedures

The procedure for conducting the Beijing Migrant Workers Survey were to go to an area expected to have a high concentration of migrant workers, such as a migrant neighborhood, a clothing market with many young workers, or a shopping mall with many young workers.

For this project the author primarily worked with Tang Zhi, an excellent research assistant, although on a few occasions. Copies of both the written surveys and consent forms were prepared, and a clipboard brought along to hold the surveys and forms for each surveyer. Standard procedure was to divide ourselves – for example, each taking a floor of the mall or clothing market. The survey givers would enter a small shop (or booth in the clothing markets), briefly explain who they were and what they were doing, and ask the person working in the shop to take the survey. If they agreed, they would be given a survey (and pen if needed) and told that the surveyors would return shortly. A good practice seemed to be to wait until about four people were working on the survey simultaneously before returning to the first person to see if they had it completed.

When approaching possible survey respondents the author usually said something (in Chinese) similar to: "Excuse me, could you please help me? I am a student at Tsinghua and am conducting a survey. Do you think you could take a look?" Most people were very kind, although non-respondents usually said that they were too busy, or were working. After retrieving the surveys each respondent was given a copy of the consent form. Although waiver of informed consent had been obtained from the IRB, it was desired for respondents to understand the purpose of the study and be able to contact us with any questions. Most respondents appeared glad to receive the consent form and several respondents were seen reading it afterwards.

3.1.4 Data Analysis

After collecting all of the written surveys, responses were entered into Excel for later analysis. While still in China, Tang Zhi assisted with orally translating the written Chinese responses, which were then written in English directly on the hard copies of the surveys.

Most survey responses were multiple-choice, so answers were coded with a 0, 1 or 2, for yes, no, and I'm not sure. Some survey responses allowed for multiple answers (for example, types of fuel used for cooking). Responses left blank were marked as such. One issue that was challenging is that some respondents didn't realize that the survey was on both sides of the paper, so rather often left the back side blank. If this was realized, respondents were usually asked them to fill out the other side. However, occasionally if it was sensed they didn't want to be bothered anymore the form would be taken as-is, since the most important demographic, income, and fuel use questions were on the front side.

3.1.5 Limitations

Awareness of the level of non-respondents was maintained, with the non-response rate for the Beijing Migrant Workers Survey ranging from an estimated 25-50 percent. There did not appear to be a significant difference between people who were willing vs. not willing to take the survey, but of course possible differences between respondents and non-respondents cannot be clearly determined. Selection bias definitely did occur in the survey as people who seemed to fit the demographic were specifically selected, and often those who seemed friendly and willing to respond were selected (Lohr). Other causes of selection bias could include selecting a "representative" sample, misspecifying the target population, failing to include all the target population in the sampling frame (undercoverage), substituting a respondent based on convenience, and allowing the sample to be entirely volunteers (Lohr, pp. 4-7). Since the sampling method was not statistically significant, these surveys could in fact be considered questionnaires, which may be used to gain a better understanding of a specific context without applying findings to an entire population (or sampling frame) (McGuirk & O'Neill, 2005, pp. 154-155).

Additional problems that can occur with surveys (and no doubt occurred in this one) include the following: people sometimes do not tell the truth, do not always understand the questions, give different answers to different interviewers, and sometimes just forget (for example, when a traumatic event happened). Respondents also sometimes say what they think the interviewer wants to hear, or will impress them. Additionally, different interviewers may conduct the survey or interview differently, for example, by letting their emotions about a question or topic come through. Certain words may be interpreted by respondents differently, and question wording and order also have a large impact on responses (Lohr, pp. 8-10).

3.2 Data Analysis: Beijing Surveys

Once all the Beijing Migrant Workers Survey data was transferred from the paper survey copies and entered into Excel, responses that were unclear were removed as followed.

Table 3: Data removed from Beijing surveys

Number Removed (n=191 originally)	Reason
2	Seemed to copy from each other at time of surveying.
23	Beijing is their hometown.
1	Hometown of Korea.
1	Hometown of Hong Kong.
4	17 years old – too young.
5	People who already had a Beijing hukou (1 from Hebei, 1 from Hubei, 3 with hometown blank).
17	People with blanks for heating and/or cooking fuel types in Beijing and/or at home.
1	Person who had lived in Beijing their entire life.
34	Left their monthly income blank.
Total Removed: 88	**Total remaining: n= 103**

This left 103 final useable survey responses. At the same time, averages of written responses for income were taken for clarity. For example if a respondent wrote 2000-3000, 2500 was used. If they said more than 2000, or about 2000, 2000 was used. Once the responses were culled down to the usable 103, patterns were analyzed for each type of question as follows.

3.3 Survey Results

3.3.1 Gender and Age

Total average age was 25.68 years. The majority of respondents surveyed were women. The overall number of years planned to stay in Beijing was 11.51 years, although this only the average of respondents who wrote a numerical answer; a number of people wrote ‘a long time’, ‘I don’t know’, or ‘I’m not sure’.

Table 4: Beijing survey results - gender and age

Gender	Number	Percentage	Average Age	Average Number of Years in Beijing	Average time planned to live in Beijing
Male	18	17.48	29.00	5.75	16.57
Female	67	65.05	25.14	4.77	12.00
Unreported	18	17.48	24.28	4.32	3.00
Totals	*103*	*100*	*25.68*	*4.86*	*11.51*

The majority of respondents were between 18 and 30 years of age, with only 3 respondents above age 40.

Table 5: Beijing survey results - age range

Age Range	Number	Percentage
18-22	36	34.95
23-30	46	44.66
31-40	15	14.56
41-50	2	1.94
Above 50	1	0.97
Blank	3	2.91

3.3.2 Education

Approximately half the respondents had attended high school, with an additional 38% attending some, or graduating from, college.

Table 6: Beijing survey results - education

Education Level	Number	Percentage
No formal education	1	0.97
Elementary school	1	0.97
Middle school	16	15.53
High school	42	40.78
College	39	37.86

3.3.3 Hometown

Survey respondents were from 16 (out of 22) provinces, plus 4 (out of 5) Autonomous Regions and one municipality (Shanghai). Missing provinces were Gansu, Guizhou, Hainan, Hunan, Qinghai and Yunnan. The only missing autonomous region was Tibet.

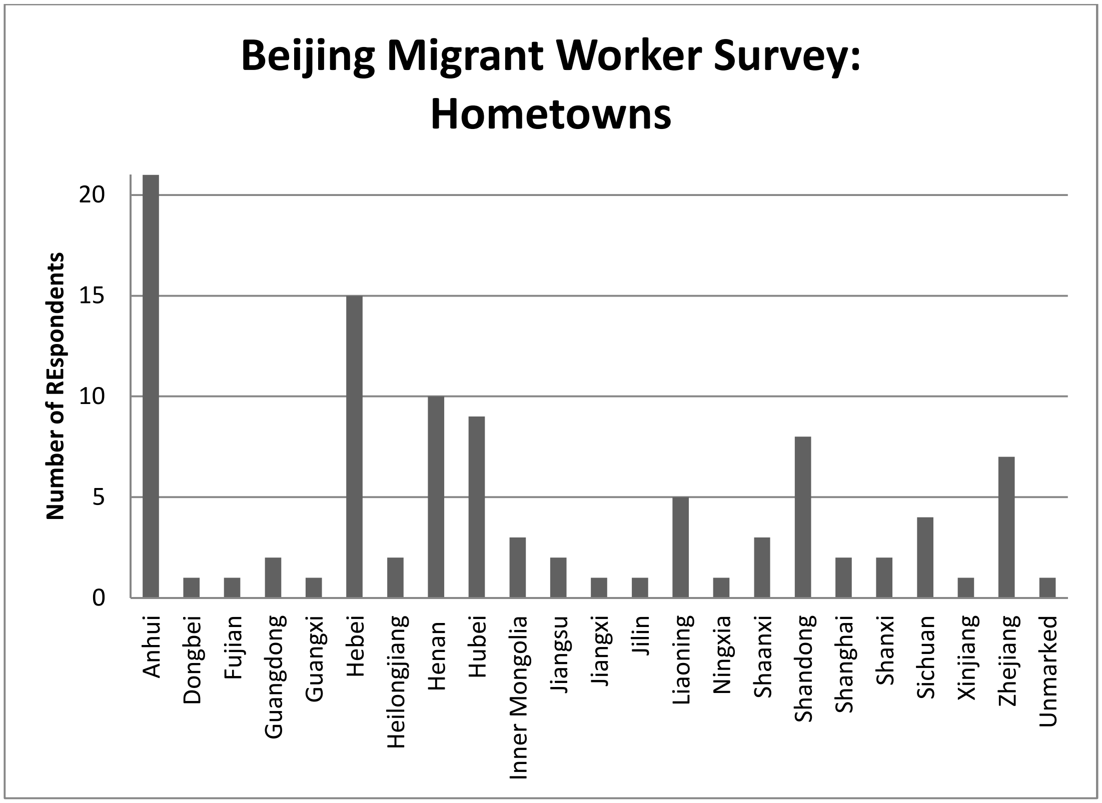

Figure 2: Beijing survey results - hometowns

Table 7: Beijing respondents' hometowns

Home Province, Area or Autonomous Region (AR)	Number of Respondents
Anhui	21
Dongbei (Area)	1
Fujian	1
Guangdong	2
Guangxi (AR)	1
Hebei	15
Heilongjiang	2
Henan	10
Hubei	9
Inner Mongolia (AR)	3
Jiangsu	2
Jiangxi	1
Jilin	1
Liaoning	5
Ningxia (AR)	1
Shaanxi	3

Shandong	8
Shanghai (City)	2
Shanxi	2
Sichuan	4
Xinjiang (AR)	1
Zhejiang	7
Unmarked	1

The geographical diversity of hometowns shows what a melting pot Beijing is – people from all over China have come to the city to work and begin creating a new life for themselves and their families. The specific areas people came from is not that significant, since this is a small and non-representational sample. However, clusters of workers from a certain area or province rather may indicate the likelihood of migrant workers living and working close to neighbors or relatives from back home. For example, a section of a large clothing market may have had a large number of respondents from Anhui, because these workers had helped to recruit, welcome and make a way for their friends and family from back home to come to Beijing.

3.3.4 Income and Spending

Average reported income was ¥3,419.42 per month, although this was dependent on educational level, as explained below. Average reported spending was ¥2,068.37 per month, or 60.49% of income. The average of the differences between each respondent's estimated average monthly income and spending was ¥1,282.83. This is a significant amount, and could represent a combination of savings and remittances back home. In the case of respondents with children living back in their hometown, it very likely is connected to school fees and other expenses for their children and the grandparents or other relatives taking care of them.

Given that the poverty line for China is about ¥3000 per year, the fact that these workers could be saving up as much as ¥1,000 per month is significant, and drives home the fact that migration is in fact sustaining rural China in many ways.

3.3.5 Appliances

Respondents were asked to check which appliances they owned in Beijing. The following shows the percentage of respondents stating that they owned a given appliance.

Table 8: Appliances owned

Appliance	Number	Percentage
Induction cook plate	72	69.90
DVD player	37	35.92
Bath with water heater	67	65.05
Fans	78	75.73
Washing machine	79	76.70
Refrigerator	73	70.87
Rice cooker	86	83.50
Computer	81	78.64
TV	76	73.79
Electric car	32	31.07
Other	11	10.68

Appliances reported as ‘other’ included in part hairdryer, microwave oven, air conditioner, and speakers. A graph of the results is shown below.

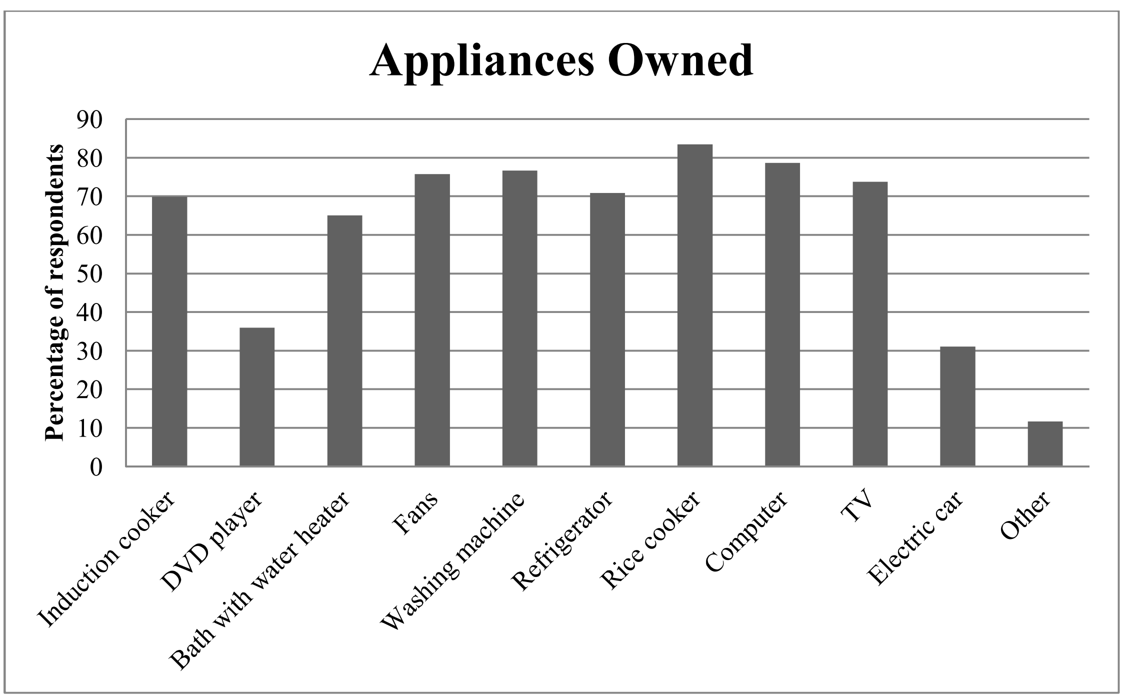

Figure 3: Appliances owned

Respondents owned from one up to 12 different appliances, and the average number of appliances was 6.73. By evaluating the average income for the number of appliances owned, a clear correlation between income and appliances owned was seen. In the graph below, the values for 11 and 12 appliances owned were removed as possible outliers.

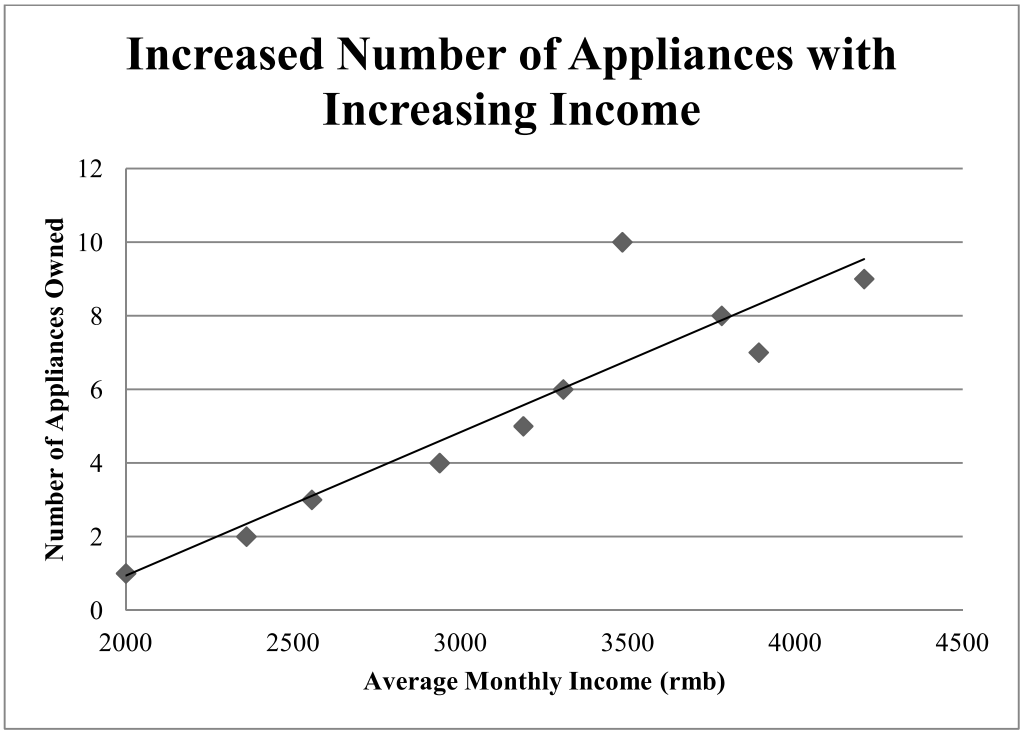

Figure 4: Increased number of appliances with increasing income

The equation for the linear correlation between income and appliances owned, with an R^2 value of 0.8354 was:

$$Number\ of\ Appliances\ owned = Average\ Monthly\ Income * (0.0039) - 6.8559$$

3.3.6 Marriage and Children

Of the respondents, 30.10 percent reported being married, and 67.96 percent reported being unmarried. Two respondents left the marriage question blank, although one of them reported having three children living in their hometown. Another respondent reported being not married but having one child living with them.

There were 24 people that reported being married and having children. Most of them (19 respondents) reported having one child, four had two children, and one had three children. Of these 24, 11 of them said their children lived with them in Beijing, 12 reported their children lived in their hometown and one left the question blank.

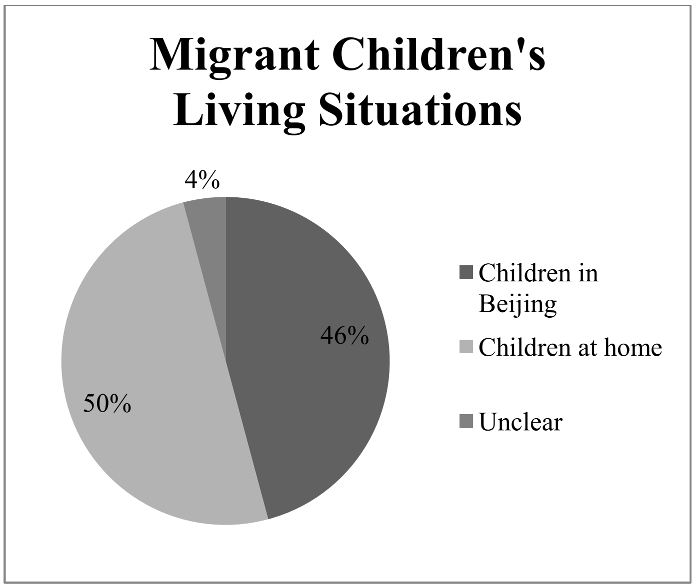

Figure 5: Migrant children's living situations

The issue of having children at home is a very important one for migrant workers, as they face difficult decisions about leaving their children behind balanced with struggling to find education for them in Beijing.

3.3.7 Desire for Beijing Hukou

Respondents were asked if they currently had a Beijing hukou, and if not, if they wanted to have one. This is important, because the hukou issue is one of the key migration issues in China today (see Chapter 2). While many researchers feel that migrant workers strongly want to have a city hukou, to ensure benefits for themselves and especially their children, 52% of these survey respondents stated they did not want a Beijing hukou. This may be due in part to the feeling that a Beijing hukou is something of an impossibility for a migrant worker to actually obtain.

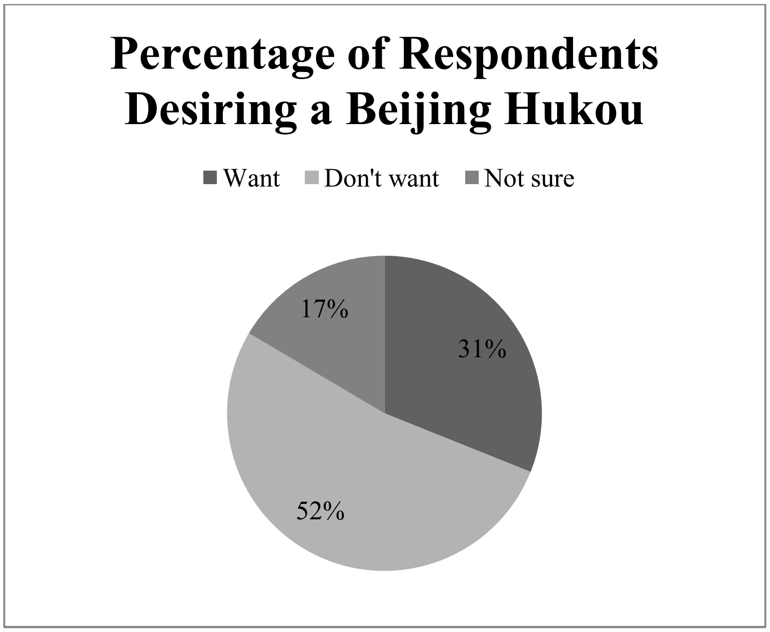

Figure 6: Percentage of respondents desiring a Beijing hukou

Indeed, the written responses to ‘why or why not’ bore this out. Respondents who said they did not want a Beijing hukou said things like: “Beijing has too many people, I don’t want to join in”; “I don’t plan to stay in Beijing”; “My heart is not settled down”; “It’s too far away from home”; “Beijing’s air is so terrible. My hometown’s better!”; “There’s a lot of pressure being in Beijing, the air is not very good and the houses are small” and “Because it is impossible, so I don’t want it”.

People who said they did in fact want a Beijing hukou said things like: “If we have a Beijing hukou we can do everything easier”; “It’s easier for children to go to school, and to buy a car”; “It’s easier to buy a home and a car”; “I want to settle down in Beijing”; and “It’s easier for children to go to school”. This variety of responses shows that migrant workers can be torn about whether or not they really do want to stay in Beijing. While some really do want opportunities for their children, others recognize the challenges of living in a big, crowded, and expensive city, and miss their hometowns.

3.3.8 Knowledge of What Renewable Energy Is

Respondents were asked to choose the correct definition of renewable energy from one of five possible answer choices. A number of respondents chose more than one answer, so only people who only chose the correct answer were marked as correct. Only 43% of respondents chose the correct answer as shown in the chart below.

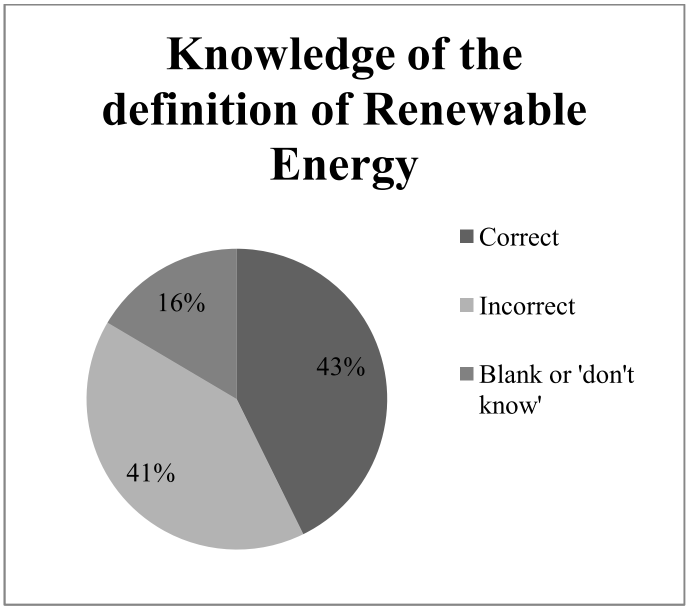

Figure 7: Knowledge of the definition of renewable energy

One of the research questions this project wanted to answer was if education about renewable energy would affect energy consumption patterns. Because this migrant workers survey asked questions both about solid fuel use for cooking and heating, as well as if respondents understood what renewable energy was, the data can be examined to see if understanding of renewable energy correlates with solid fuel use.

Table 9: Answers to renewable energy question

Question: Which of the following gives the correct definition of renewable energy?	Number of respondents	Percent using at least one type of solid fuel for cooking	Percent using at least one type of solid fuel for heating
Correct	44	25.00	6.82
Incorrect	42	16.67	14.29
Blank or 'don't know'	17	17.65	11.76
Total incorrect	59	16.95	13.56

From these responses it can be seen that an understanding of renewable energy was connected with a lower percentage of solid fuel use for heating, but a higher percentage of solid fuel use for cooking. From these results it seems like there is not a strong link between understanding what renewable energy is and using solid fuels.

Since many respondents use a mix of solid and non-solid fuels, there may be a stronger connection between knowledge of renewable energy and use of non-solid fuels for home heating and cooking in Beijing.

Table 10: Definition of renewable energy and fuel use

Question: Which of the following gives the correct definition of renewable energy?	Number of respondents	Percent using at least one type of non-solid fuel for cooking	Percent using at least one type of non-solid fuel for heating
Correct	44	88.64	65.91
Incorrect	42	85.71	69.05
Blank or 'don't know'	17	88.24	58.82
Total incorrect	59	86.44	66.10

From these results it can be seen that there is not a significant difference between use of non-solid fuels for cooking and heating among respondents who did and did not clearly understand the definition of renewable energy.

3.3.9 Cooking and Heating

Average estimated overall monthly winter heating costs were ¥380.35. Average estimated monthly cooking costs were ¥318.45. When asked if they had heating in their homes, 80.58 percent of respondents replied they did. A reported 77.67 percent cooked with electricity (as one at least of their cooking fuels).

3.3.10 Education, Income, and Solid Fuel Use

One of the main goals of this research is to evaluate correlations between education, income, migration and solid fuel use. By comparing migrant workers' solid fuel use in Beijing to their solid fuel use at home, it was found that the percent of people using at least one type of solid fuels for cooking drops by more than half when they migrate to the cities. Additionally, it is seen that having a college level of education versus a middle-school income also decreases use of solid fuel by about half. Equations for the correlation of solid fuel use for cooking and educational level in Beijing and workers' hometowns are shown below.

$$\text{Percent of people using solid fuels for cooking in their hometown} \\ = \text{Education level} * (-14.58) + 108.55$$

$$\text{Percent of people using solid fuels for cooking in Beijing} \\ = \text{Education level} * (-7.93) + 54.41$$

The correlation for income and education for respondents is as follows.

$$\text{Income} = \text{Education level} * ¥561.22 + ¥1{,}068.20$$

The total results are shown below. Educational levels represented by 3, 4, and 5 represent middle school, high school, and college respectively.

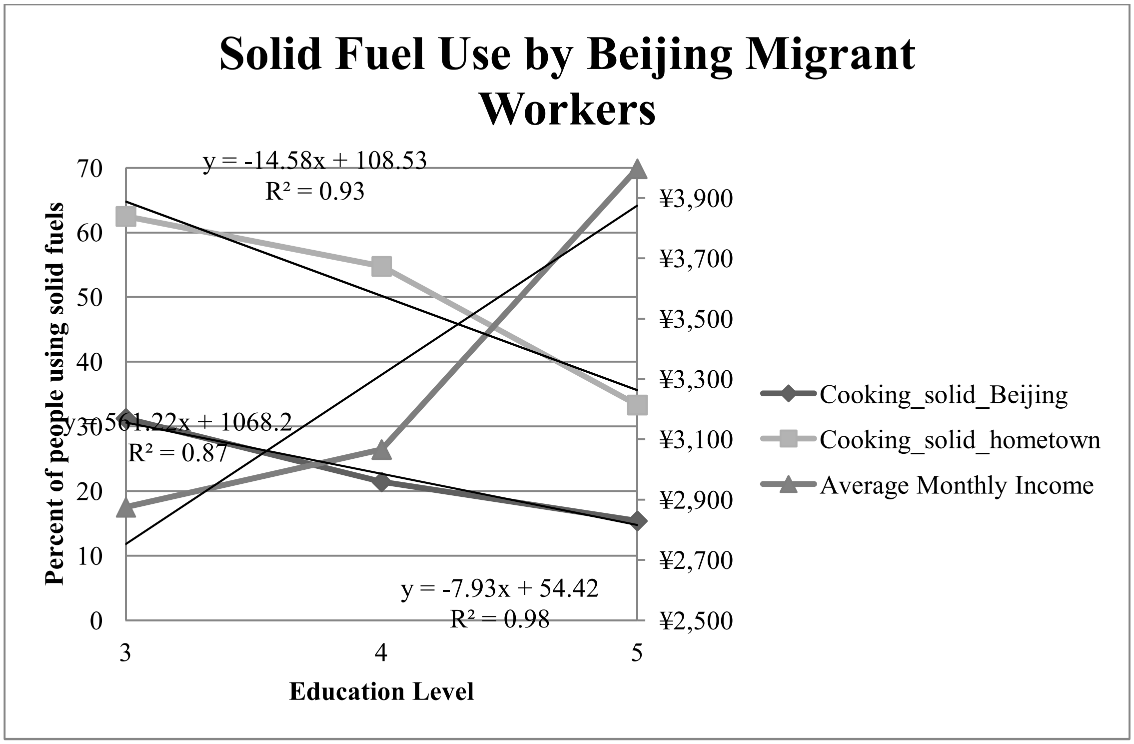

Figure 8: Solid fuel use by migrant workers in Beijing and in their hometowns

Values for Beijing worker's incomes and rural incomes cannot be directly compared at first, since the Beijing survey asked for estimates of monthly income, and the Tsinghua rural energy survey asked for yearly income. However, by multiplying the Beijing monthly estimates by 12 and recalculating, the following is found:

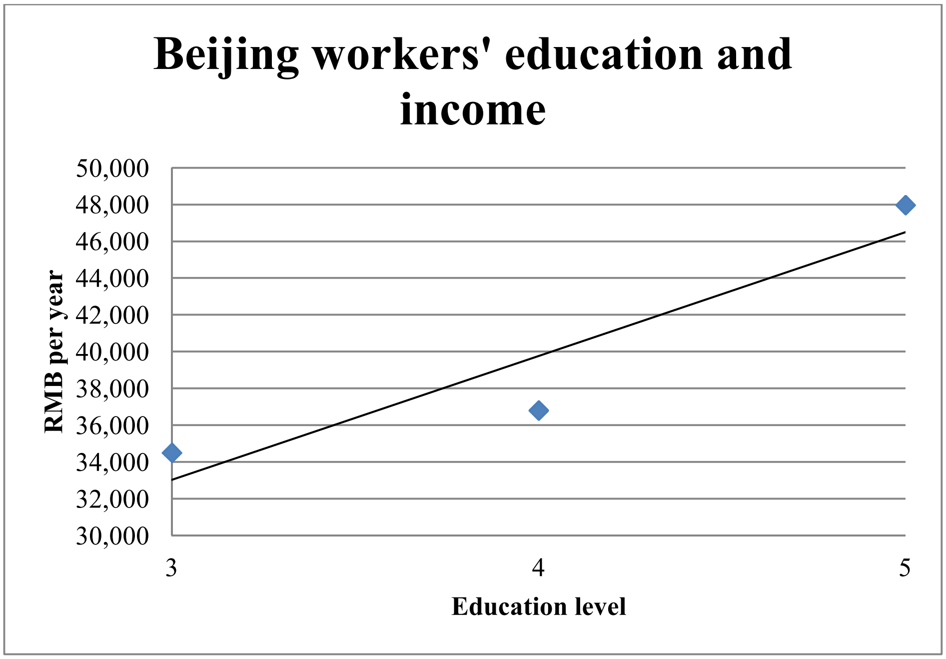

Figure 9: Beijing migrant workers' education and income

The equation for migrant workers' yearly income is thus

$$Income = Education\ level * ¥6{,}734.40 + ¥12{,}818.00$$

with a R^2 value of 0.87. This value was used in the agent-based model to predict migrant workers' income levels. These results put Beijing migrant worker's yearly salaries closest to those earned by workers in the rural areas surrounding the cities of Tianjin and Beijing as shown in the figure below.

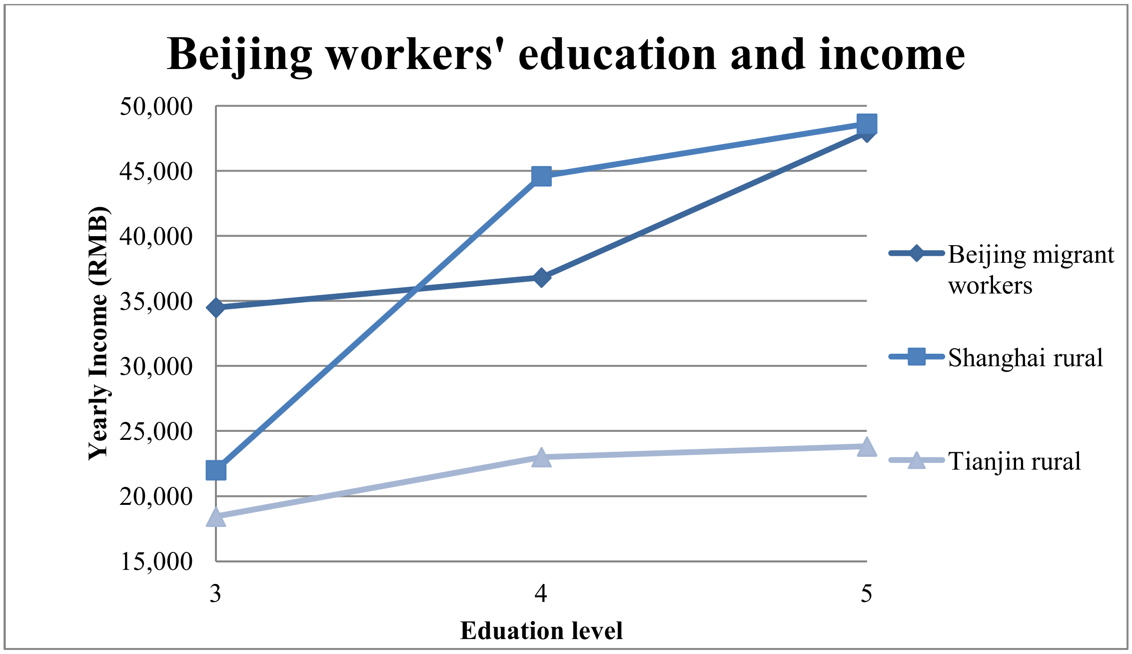

Figure 10: Beijing migrant workers' income as compared to rural areas of Tianjin and Beijing

3.3.11 Energy Choice Factors

One of the goals of this work was to evaluate which choice factors were most influential in rural families' decisions of which energy to use. In the Beijing Migrant Workers Survey, respondents were also asked about factors influencing their choice of energy. Respondents were asked to rank five possible factors in order of influence from one to five, with five being the least important and one the most important. The five factors were: ease of use, what their neighbors were using, cost, impacts on their health, and effect on the environment.

Because of a printing error, the line next to the first factor 'neighbors' (where respondents were supposed to write the ranking number) was missing, so most respondents only wrote the numbers 1-4. However, 100 percent of the ten respondents who wrote in the number 5 followed by 1 through 4, put 'neighbors' as their fifth-ranked choice. Based on previous experience surveying in Beijing and rural areas in other surveys, responses to this question tend to follow this pattern and usually put 'neighbors' as their last-ranked choice.

This type of question generally proves challenging for respondents, and only 47 of 103 respondents (or 45.6 percent) answered the question in correct rank-order format. Assuming that respondents who did not write 5 would have put 5 for the 'neighbors' category, results show that respondents rank health as their most important factor, followed by cost, ease of use, environmental impacts, and lastly what their neighbors are using, if average rankings are compared.

Looking at the percentage of respondents that choose '1' for different factors, the picture is slightly different, with the order of importance being health first, followed by ease of use, environmental impacts, then cost. No one (not even the respondents who listed five responses) wrote neighbors as their most important choice, showing that this was not an important factor in their choice of energy.

Table 11: Ranking of energy choice factors

	Neighbors	**Environment**	**Ease of Use**	**Cost**	**Health**
Average Ranking	5.00	3.02	2.49	2.45	2.04
Mode	5	3	3	4	2
Number of respondents who chose '1' (*n* = 47)	0	12	13	8	14

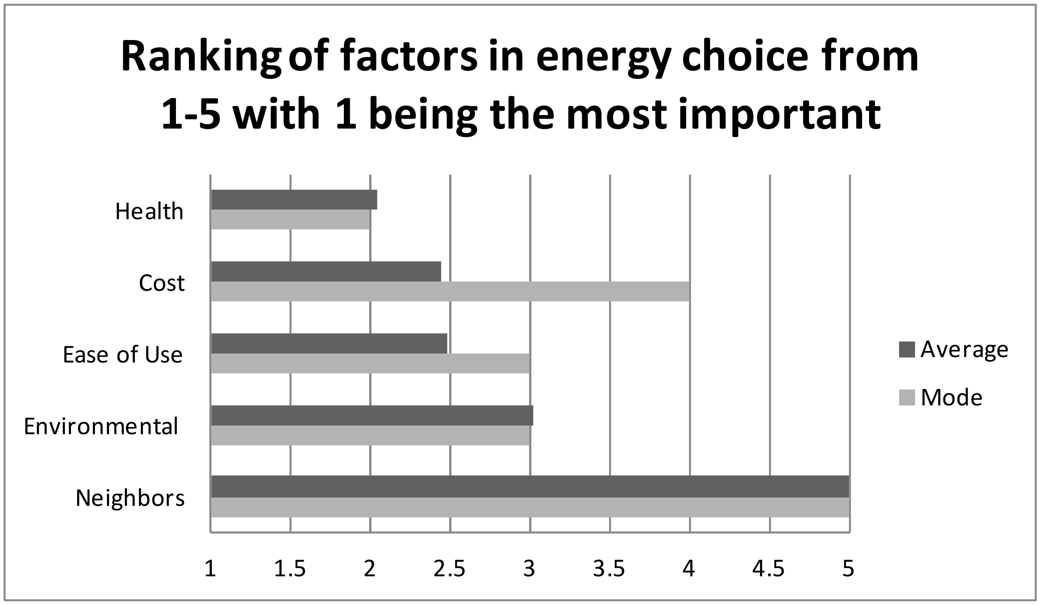

Figure 11: Ranking of energy choice factors

3.3.12 Written Responses: 北京太大， 我很小

At the end of the survey, respondents were given a few blank lines in which to share their opinions about life in Beijing. The goal of this part of the survey was to obtain a richer insight into the personal life and challenges of migrant workers. A favorite survey response from this whole study (which was actually given in response to another section of the survey) is 北京太大，我很小. (*Beijing tai da, wo hen xiao).* Beijing is too big, and I am very small.

The question posed to workers at the end of the survey was:

我们想了解更多关于北京的生活 - 好的和坏的。您可以分享任何关于外来务工人员在北京的生活，我们对此都非常感兴趣。非常感谢您的支持！

(We want to know more about Beijing's life - good and bad. You can share any information about migrant workers living in Beijing, and we are very interested. Thank you for your support!).

The written answers to this final survey section provide a good insight into some of the challenges facing migrant workers in Beijing, and their views of the city. A sampling of their written responses is given in English and Chinese below. Issues that came up time and time again were the air quality of the city, crowdedness, and the extremely high costs of homes, cars, and living expenses.

坏的：北京的生活压力太太太大了，压得人喘不过气 每个月交完房租，除去饭费就剩不了多少钱可以由自己任意支配了！

好的：玩的地方多，比家乡有趣的地方多！

Living in Beijing the pressure is too too too high! We can't breathe (because the stress is too heavy). After rent and food there is almost nothing left over. There are more interesting places to play than in my home city.

空气污染严重不利于健康，车多，噪声大

Air quality is so terrible, so bad for people's health, so many cars, too noisy.

我来北京的时间不长，但是有很多的不喜欢

不喜欢这里太拥挤的人群，不喜欢这里非常不卫生的饮食（尤其是地铁周边的小摊位），不喜欢太多的高楼大厦（以至于想买什么东西都不知道去哪），不喜欢粗俗暴躁的骂人者（东北人居多）

I'm not live here for long but there's something already especially give me a real pain in the neck: there are so many people squished together; very unhealthy diet (like from the booths around the subway station); there are a lot of high buildings and if I want to buy something I don't know where I should go; the vulgar and irritable people (most of them from the northeast).

北京交通很方便，现在人们都坐地铁上班，那样很好，有利于环境生长，减少空气污染

Beijing traffic is very convenient, and now people have to take the subway to work, so good, environmentally sound growth, reduce air pollution.

交通拥挤，出去游玩太过浪费时间，不如呆在家里宅 人口众多，素质不一，影响市容 道路肮脏，空气质量差物价相对其他城市便宜稳定，交通费便宜 房租不菲

Traffic is so crowded - it's better to stay home, do everything there; going out takes such a long time. There are so many people, the people's quality is really different, some high, some low - it effects the city. The road is so dirty, the air quality is so terrible. Compared to other cities, the price for everything is cheaper, and the price is steady. Transportation is cheap, but the houses are expensive.

北京消费高，收入低，交通不便，环境差，由于尾气污染，二氧化碳，铅在空气中的含量过 高

但北京整体素质比较高

The quality of life in Beijing is better than other cities; Life expenses are too expensive, cost of living is too high, terrible traffic, terrible environment; because of the exhaust from the car there is a lot of CO_2, and lead in the air is too much.

我想实现自己的理想 我觉得北京的人文环境非常棒，文化氛围好，如果大气污染能再治理好些就更棒了，我爱北京！

I feel Beijing's cultural environment is very good, the atmosphere of the culture is great; If the air pollution can be managed better, that will be great. I love Beijing!

刚来北京，下了汽车，第一感觉就是这个城市太大，自己反而却非常渺小刚开始找工作时也会有些自卑，城市太大人情味太淡 房租、生活中所有的必需品也会让我们在购买考虑很多，价格对我们来说是非常重要的人的成功真的是一件很难的事尤其是不靠任何人，用自己的双手挣每一分钱，虽然很累，但很自豪！！生活生活，活着就得干活！！

My first impression when I got off the car was that the city was really big, and I felt really small; sometimes felt like I wasn't worth much; everything I have accomplished and I have gained has brought me a lot of pride; live life to the fullest!!

3.4 Regression Analysis of Factors Predicting Solid Fuel Use

3.4.1 Statistical Methods

Statistical analysis of both the Tsinghua data and the Beijing migrant workers data set was conducted separately in R but the same procedures were followed for each set. When conducting data analysis in R, three steps were followed:

1. GLM with logit: multiple linear regression to establish how specific variables (income, education, etc. predicted the output factor (solid vs. non-solid fuels).
2. Step AIC: determine which combination of these variables best and most succinctly accurately predict the output variable.

3. Chi-squared testing: ensure that each variable included within the “stepAIC” combination was statistically significant.

In order to evaluate which factors most strongly predict solid fuel use, a generalized linear model (GLM) was applied. GLM is a generalization of linear regression and can be used effectively with a non-binary input variable that is predicting a binary output variable (for example, use of income to predict solid vs. non-solid fuel use) (Towler, 2011). When the output is binary, then the logit link function can be used, which produces the probability of a given binary outcome.

The equation for Logit analysis is (Helsel & Hirsch, 2002):

$$\text{Logit}\ (y) = B_0 + B(x)$$

The equation for the Logit function can be used to determine probability of a given factor depending on a specific x variable using the following equation.

$$P(\text{of a given factor}) = \frac{e^{(B0+B1\times xvals)}}{(1+e^{(B0+B1\times xvals)})}$$

Where B_0 is the intercept and $B_{1\text{-}n}$ are the coefficients for variables 1-*n*.

Also within R, the ‘stepAIC’ function was used to analyze which factors (and in which combination) most strongly predicted solid fuel use for heating in Beijing, solid fuel use for cooking in Beijing, solid fuel use for heating in migrants’ home towns, and solid fuel use for cooking in migrants’ hometowns. StepAIC adds and drops different factors until it obtains a model that best predicts the output factor (R Documentation).

The AIC in the StepAIC function stands for "Akaike's Information Criterion" and was developed by Akaike in the 1970s, with a paper in 1973. One goal of using the AIC is to "minimize the loss of information". As one researcher explains:

"…we must accept that there are no true models. Indeed, models only approximate reality. The question then is to find which model would best approximate reality given the data we have recorded. In other words, we are trying to minimize the loss of information" (Mazerolle).

The AIC is defined as:

$$AIC = -2(\log likelihood) + 2\,K$$

Where K represents the number of variables plus the intercept, and the log-likelihood represents the "overall fit of the model". The goal of the AIC is to find the model that best predicts the output while using the smallest number of variables (Mazerolle), (Henze, 2011).

When using AIC to examine different model options, the best combination of variables (the one the accurately predicts model outputs while using the fewest number of variables) will be the one with the smallest AIC. The same data set must be used to compare AIC values across models – you cannot compare AIC values for different model sets (Mazerolle).

The chi-squared test is used to "compare proportions between two or more groups". The equation for the chi-squared test is (Sainani).

$$X^2 = \sum \frac{(observed - expected)^2}{expected}$$

In order for a factor to be considered significant, it had to both be included in the lowest stepAIC model and be statistically significant via the chi-squared test ($p < 0.05$).

3.4.2 Preparation of Data

Because R cannot perform GLM analysis on blank values, the migrant worker data set was culled to remove rows of data that contained blank values. This left 83 responses that could be evaluated in R. Columns (questions) that did not seem applicable as contributing factors or had too many blank values in them were also removed from the data set. Factors that were analyzed via stepAIC in R were:

Table 12: Type of responses evaluated in multiple regression analysis

Factor	Type of Response
Age	Continuous
Years in Beijing	Continuous
Education level	1-5
Do you have heat in your home?	0 or 1 (yes or no)
Do you cook with electricity?	0 or 1 (yes or no)
Are you married?	0 or 1 (yes or no)
Monthly income	Continuous
Monthly spending	Continuous
Number of appliances owned	0-12
Do you have a Beijing hukou?	0 or 1 (yes or no)
Do you want one?	0, 1, or 2 (yes, no, not sure)
Heating back home (solid vs. non-solid)	0 or 1 (non-solid, solid)
Cooking back home (solid vs. non-solid)	0 or 1 (non-solid, solid)

While evaluating winter monthly heating costs and monthly cooking fuel costs would have been useful, too many of these responses were left blank to incorporate into the analysis.

3.4.3 Regression Analysis

GLM and stepAIC analysis were performed in R. Each predictor was evaluated with the 13 possible factors. After the stepAIC modeling was run, Chi squared analysis was also performed. The coefficients and intercepts were then evaluated for the factors found in the StepAIC analysis. Initial analysis showed that out of the 13 possible factors the top five were: heating back home, cooking back home, income, education, and number of years spent in Beijing. These top five factors were then analyzed in more detail. Results are shown in the table below[11].

Table 13: Top predictors for solid fuel use by migrant workers

Predictor	Top Predictive Factor(s)	Step AIC Value	Coefficients and Intercept	P-Value
Heating solid fuels: Beijing	Solid cooking at home	57	+2.3*solids cooking at home -3.7	0.006
Cooking solid fuels: Beijing	Solid cooking at home, years in Beijing	78	+2.1*solids cooking at home -0.2*years in Beijing -1.7	Solid cooking at home (0.0008) Years in Beijing (0.016)
Overall solid fuel use	Solids cooking at home, solids heating at home, years in Beijing	23	+30*solids cooking at home +29*solids heating at home - 0.9*years in Beijing -0.2	Solids cooking at home (< 2.2 e-16) Solids heating at home (9.8 e-06) Years in Beijing (0.03)

These results provided a very interesting and completely novel look at fuel use among migrant workers in Beijing. Several applications for development work and theory can be gleaned from these results.

- While it may be assumed that once rural people move to the city they switch to using clean energy right away (like city dwellers) these results show that in fact it can take a number of years for migrant workers to change their energy use and it is actually a slower process.

[11] A note about AIC values: AIC values can only be compared through runs of the same data to predict the same factor, not across different modeling runs. They are used to evaluate which set of factors best predicts a given output – the AIC value which is lowest for a given set of factors mean that set best predicts the output. This type of AIC evaluation was used to determine which the top predictive factors were for three different outputs. In this case, the AIC values are examining different outputs (heating, cooking and overall use) so they cannot be compared.

- It's well known in international development research that behavioral change is one of the most complex and challenging aspects of introducing new technology. This research serves to confirm that people are indeed used to using the types of fuels they use back home (or grew up using) and change is hard.

3.4.4 Probability of Solid Fuel Use by Migrant Workers

Use of the top predictive factors for overall solid fuel use, with their coefficients and intercept can be used to calculate the probability of overall solid fuel use (for cooking and heating) for migrant workers in Beijing based on their fuel use back home and the length of time they have lived in the city. The equation is shown below.

$$P = \frac{e^{(30*solid\ cooking\ at\ home+29*solid\ heating\ at\ home-0.9*years\ in\ Beijing-0.2)}}{1+e^{(30*solid\ cooking\ at\ home+29*solid\ heating\ at\ home-0.9*years\ in\ Beijing-0.2)}}$$

The values for solid cooking and heating at home are binary, with 1 meaning solid fuel of some sort is used, and 0 indicating that it is not. Number of years in Beijing is numeric from 0 onwards. Based on this equation, the impact of the fuel type used at home is so significant that it takes about 25 years before the "years in Beijing" factor begins to be an impact[12] and decrease the overall probability of solid fuel use as seen in the figure below.

[12] This only holds true if solid fuel is used for either cooking or heating at home. If it was used for both, it takes roughly 55 years before a decrease in solid fuel use in Beijing is seen.

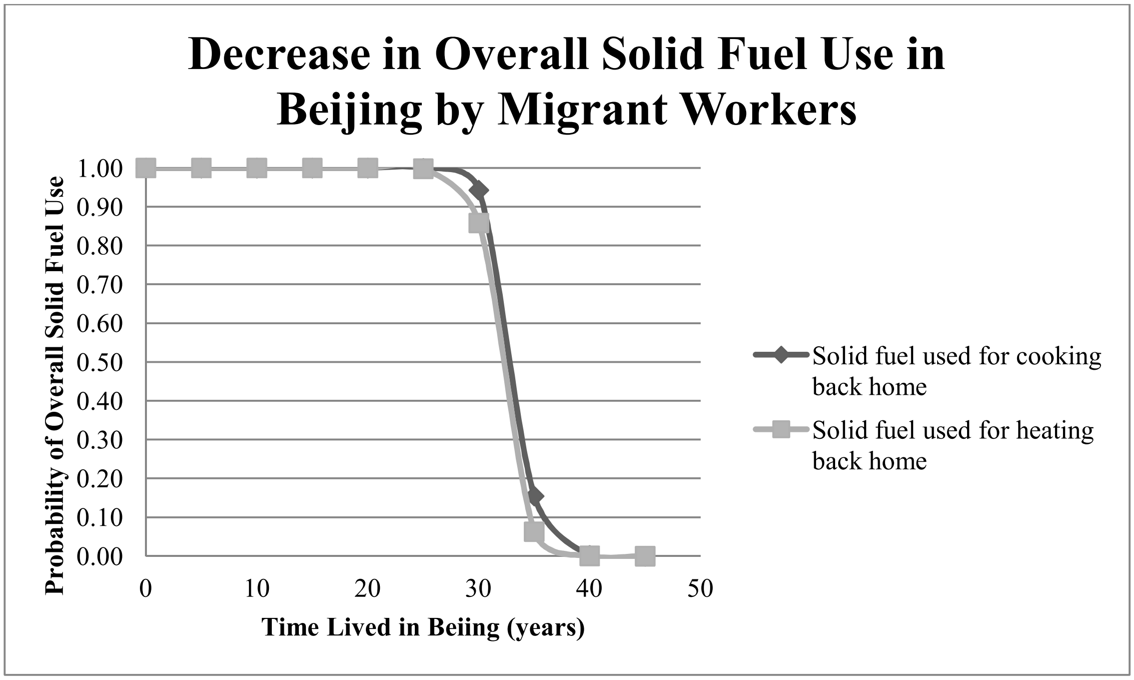

Figure 12: Decrease in overall solid fuel use in Beijing by migrant workers

3.5 Discussion of Beijing Migrant Workers Survey

The Beijing migrant workers survey, despite being a small sample size, provides many insights into the lives on migrant workers in China's capital city, and especially shows how education and income are linked to solid use in Beijing and in migrant worker's hometowns.

In China today, migrant workers send a huge amount of money home to their families. This socioeconomic situation of sending remittances home is illustrated in the survey results by the large difference between average amount spent and income earned, showing that many migrant workers do likely save and/or send home a significant portion of their income.

Written responses about respondent's desires (or not) to have a hukou, as well as their answers to the final survey question give insights into some of the challenges facing migrant workers in Beijing. Finding that roughly half of respondents with children have their children living back in their hometowns helps to explain both the remittance issue as well as some of the confusing feelings workers may have towards dreaming of obtaining a Beijing hukou.

Correlations between solid fuel use for cooking and education and income show that by moving to the city, a migrant worker's solid fuel use can drop by as much as half. Additionally, the percentage of people using solid fuel who have a college education (or have attended some college), is roughly half again the percentage of those who have just attended middle school. This makes a powerful argument for the importance of education – since it is known that use of solid fuels is a leading cause of disease, education really can save your life.

It's interesting to observe that the predictor for using solid fuels for heating in Beijing is not the use of solid fuels for heating but rather for cooking. This may be because some respondents are from southern provinces where the heating burden is much lower. However, while they may not use solid fuels at home for heating, the familiarity with use of solid fuels for cooking in Southern areas may transfer over to use of solid fuels for heating in Beijing.

CHAPTER 4
TSINGHUA RURAL ENERGY SURVEY: METHODS AND RESULTS

4 Tsinghua Rural Energy Survey: Methods and Results

4.1 Tsinghua Rural Energy Survey: Overview

Permission was granted by Dr. Xudong Yang to use the Tsinghua Rural Energy Survey Data which had been collected by Tsinghua students under his oversight in 2006 and 2007. This survey was conducted in the winter of 2006 and summer of 2007. These surveys asked different questions in 2006 and 2007, with some questions the same in both years. This data can give a broad overview of conditions for families across different provinces in China, as well as be analyzed for predictive purposes, particularly in the areas of correlating education and income, and income and fuel types used for cooking and heating. This data set can also be used to analyze which factors have the greatest impact on rural families choice to use solid or non-solid fuels. An overview of these survey results can be found in Yang 2010 (Yang, Jiang, Yang, & Shan, 2010).

4.1.1 Participants

The survey was conducted by the Building Energy Research Center of Tsinghua University, and supported in part by the Chinese Ministry of Agriculture. It covered 15 northern provinces (88 rural counties) and 9 southern provinces (62 counties) (Yang, Jiang, Yang, & Shan, 2010). Participants were families in rural areas[13]. Overall responses totaled more than 4300.

[13] All survey data is from areas classified as rural, so even in the case of cities such as Shanghai, Beijing, and Tianjin, the data is not from urban residents but rather from people in areas surrounding the city but still categorized as a rural district.

4.1.2 Instruments

The 2006 and 2007 survey differed in some respects. Survey questions included window-to-wall ratio, perception of smokiness in the kitchens, heating fuel and equipment, cooking fuels and equipment, education, and income.

4.1.3 Procedures

Roughly 700 students from Tsinghua University conducted the survey, supervised overall by Dr. Yang and his graduate students. Dr. Yang's group and the students worked closely with the local governments to identify homes to survey, and the students also documented the homes with photographs.

4.1.4 Data Analysis

The first step in processing the Tsinghua survey data was to translate it into English. This was originally done with the assistance of fellow graduate students at Tsinghua University, and later with the help of Google Translate. Northern and Southern data files were kept separate, as the surveys were conducted at different times and asked different questions.

Original data analysis in 2008 focused on finding trends between income and education levels, and energy use and income. Regression analysis was performed to evaluate effects of income, family size, and education levels on use of solid vs.. non-solid fuels for heating and cooking separately. Solid fuels were coal, wood, straw and biomass, and non-solid were LPG, electricity and marsh gas (or gas from a biodigester). The percent of households using just solid fuels, just liquid fuels, and both were analyzed for both northern and southern provinces. Strong correlations between income and education were found, as well as an example of the "Energy Ladder" concept, showing that as family income increased, families tended to use more expensive, or cleaner, fuels.

4.1.5 Limitations

Some challenges of working with the Tsinghua survey data are sections of missing data. Entire provinces are missing entire blocks of questions, for reasons that aren't entirely clear. Additionally, there are differences between the questions asked in the northern and southern surveys, which makes it challenging to compare some of the parameters country-wide. Self-reporting of income may be a difficult issue as survey respondents may under or over report income based on their motivations. An additional challenge is the use of multiple fuels, but this can be addressed by separating out responses into the specific different fuel types.

4.2 Income and Education Correlations

4.2.1 Overview of data

One of the first steps in developing the agent-based model was to establish correlations between education and income for each of the provinces surveyed, and then correlating income levels with solid versus non-solid fuel type. Fuel type then in turn has a significant impact on health outcomes.

For each of the Northern and Southern data sets, data was sorted and respondents which did not have both income and education columns filled in were removed. Income levels under ¥200/year and over ¥100,000/year were also removed. There were only a few respondents with income levels less than ¥200/year, and the accuracy of these responses was unclear. Income levels above ¥100,000/year were removed from the data sets as there were very few responses with incomes over this level.

One challenge in preparing the data is that many families use a mixture of heating equipment and heating fuels, as well as cooking equipment and cooking fuels. Since multiple responses were entered within one response cell, these needed to be sorted out to separate columns in order to examine which fuel and equipment combinations each family is using for heating and cooking. Responses were sorted text-to-columns, width delineated, to clearly separate out fuel and equipment mixtures into separate columns, so that solid vs. non-solid fuels can be sorted effectively.

For both the Northern and Southern data sets, data for education and income was separated out per province, and income reported for each level of education (levels 1-5) was averaged. Level 6 education was not included, as these responses may have been in error.

Provinces and cities surveyed in the Tsinghua survey and included in the education-income assessment were:

Table 14: Provinces and cities included in Tsinghua survey

Northern Provinces and Cities	Southern Provinces and Cities
Beijing	Anhui
Gansu	Chongching
Hebei	Hubei
Henan	Hunan
Inner Mongolia	Jiangsu
Jilin	Jiangxi
Liaoning	Shanghai
Ningxia	Sichuan
Qinghai	Zhejiang
Shaanxi	
Shandong	
Shanxi	
Tianjin	
Xinjiang	

Education levels of 1-5 and number of respondents are shown in tables below.

Table 15: Education levels in Tsinghua survey

Education Level	Amount of Education
1	Never have gone to school (未上过学)
2	Elementary school (小学)
3	Middle school (初中)
4	High school or technical college (高中或中专)
5	College or above (大专及大专以上)

Table 16: Number of Northern respondents per area

Northern Provinces	Number of Respondents
Beijing	117
Gansu	212
Hebei	151
Henan	265
Inner Mongolia	193
Jilin	78
Liaoning	109
Ningxia	38
Qinghai	143
Shaanxi	117
Shandong	313
Shanxi	76
Tianjin	22
Xinjiang	72

Table 17: Number of Southern respondents per area

Southern Provinces	Number of Respondents
Anhui	151
Chongqing	30
Hubei	200
Hunan	301
Jiangsu	218
Jiangxi	221
Shanghai	21
Sichuan	374
Zhejiang	177

4.2.1.1 Northern Education-Income Correlations

Average levels of income (in yuan/year) for the five education levels in each province are shown below. Poverty line in this table refers to the World Bank estimated poverty line of $1.25 per day, or $456.56 per year. Using the dollar-yuan exchange rate of 7.76 yuan per one USD (Chinability), this equates to ¥ 3,634.24 per year. The reported value for Beijing at education level 1 was 15,000 rmb/year but this was left out of calculations as it is suspected to be an inaccurate representation. The reported income value for education level 5 for Shandong was lower than the income levels for educational levels 3 and 4, so this was also exempted as it was viewed to be non-representative.

Table 18: Northern income and education

	Income at Different Education Levels				
Northern Provinces	1	2	3	4	5
Beijing		5,000.00	11,998.00	20,871.11	22,776.19
Gansu	3,166.67	5,088.57	6,345.68	8,087.15	13,960.00
Hebei	no data	4,225.00	10,579.82	14,346.58	20,392.31
Henan	2,833.33	8,421.74	9,692.94	11,126.67	13,876.70
Inner Mongolia	4,916.67	8,770.00	13,508.35	19,572.34	15,521.95
Jilin	5,000.00	7,357.14	12,118.57	12,688.46	17,775.00
Liaoning	13,500.00	14,437.50	15,641.38	20,930.43	23,993.33
Ningxia	2,500.00	5,416.67	3,409.09	7,750.00	8,100.00
Qinghai	no data	5,727.27	7,362.50	7,445.95	10,792.50
Shaanxi	8,000.00	12,244.44	18,262.50	22,264.71	20,729.17
Shandong	2,800.00	11,071.43	15,165.91	15,033.62	
Shanxi	600.00	3,000.00	6,437.14	6,835.19	15,100.00
Tianjin	no data	6,500.00	18,428.57	23,000.00	25,833.33
Xinjiang	no data	9,000.00	19,828.57	22,230.77	22,000.00
Average Northern	4,812.96	7,589.98	12,055.64	15,155.93	17,370.41
Average Northern without Beijing and Tianjin	4,812.96	7,896.65	11,529.37	14,025.99	16,214.68
Poverty Line	3,634.24	3,634.24	3,634.24	3,634.24	3,634.24

This data (without the poverty line) is shown on the graph below:

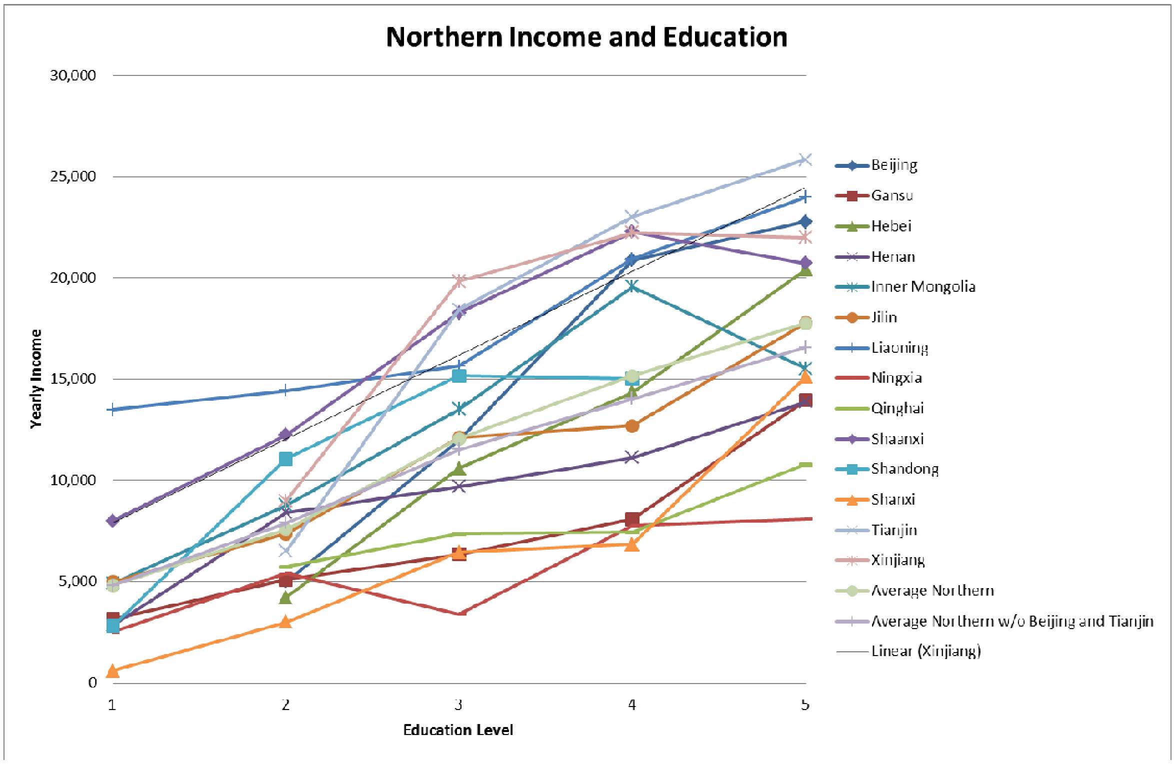

Figure 13: Northern income-education correlations

Next, income for each province was graphed as the dependent variable, with education as the dependent variable. A linear trendline was fit for each province. For consistency, linear trendlines were chosen for each province or area. Linear trendline equations and corresponding R^2 values are shown below.

Table 19: Northern correlation equations

Northern Provinces	Equation	R² Value
Beijing	y = 6220.2x - 6609	R2 = 0.95
Gansu	y = 2458.5x - 45.958	R2 = 0.89
Hebei	y = 5226.9x - 681.24	R2 = 0.99
Henan	y = 2479.2x + 1752.8	R2 = 0.92
Inner Mongolia	y = 3201.3x + 2854	R2 = 0.78
Jilin	y = 3088.1x + 1723.4	R2 = 0.96
Liaoning	y = 2748x + 9456.7	R2 = 0.91
Ningxia	y = 1353.3x + 1375.2	R2 = 0.73

Qinghai	y = 1527.9x + 2484.4	R2 = 0.86
Shaanxi	y = 3547.9x + 5656.6	R2 = 0.87
Shandong	y = 4079.5x + 818.9	R2 = 0.83
Shanxi	y = 3283.5x - 3456.1	R2 = 0.89
Tianjin	y = 6257.1x - 3459.5	R2 = 0.90
Xinjiang	y = 4140.2x + 3774.1	R2 = 0.73
Average Northern	y = 3345.5x + 1437.8	R2 = 0.99
Average Northern without Beijing and Tianjin	y = 2963.8x + 2075	R2 = 0.99

4.2.1.2 Southern Education-Income Correlations

Average yearly income at each education level was calculated as shown in the table below.

Table 20: Southern income-education levels

	Income at Different Education Levels				
Southern Provinces	1	2	3	4	5
Anhui	-	9,142.86	19,147.06	21,000.00	17,347.83
Chongqing	1,500.00	2,000.00	9,375.00	11,650.00	17,625.00
Hubei	-	8,166.67	14,080.71	16,256.10	18,630.43
Hunan	-	7,531.58	13,415.46	18,960.63	35,189.47
Jiangsu	no data	19,200.00	23,458.82	25,281.25	30,616.28
Jiangxi	-	13,666.25	16,311.88	19,820.17	21,312.00
Shanghai	no data	no data	22,000.00	44,600.00	48,636.36
Sichuan	2,309.09	5,551.58	13,257.50	13,883.50	19,000.00
Zhejiang	850.00	20,166.67	27,271.74	29,824.29	36,207.55
Average Southern	1,553.03	10,678.20	17,590.91	22,363.99	27,173.88
Average Southern without Shanghai	1,553.03	10,678.20	17,039.77	19,584.49	24,491.07
Poverty Line	¥3,451.61	¥3,451.61	¥3,451.61	¥3,451.61	¥3,451.61

Poverty line calculations were the same, but an exchange rate of 7.56 for August 2006 (Chinability) was used instead as the Southern surveys were taken in 2006 instead of 2007. Data was graphed as shown below. Differences in incomes across different provinces can clearly be seen, with rural areas of Shanghai having higher incomes than poorer areas, such as Sichuan or Hubei.

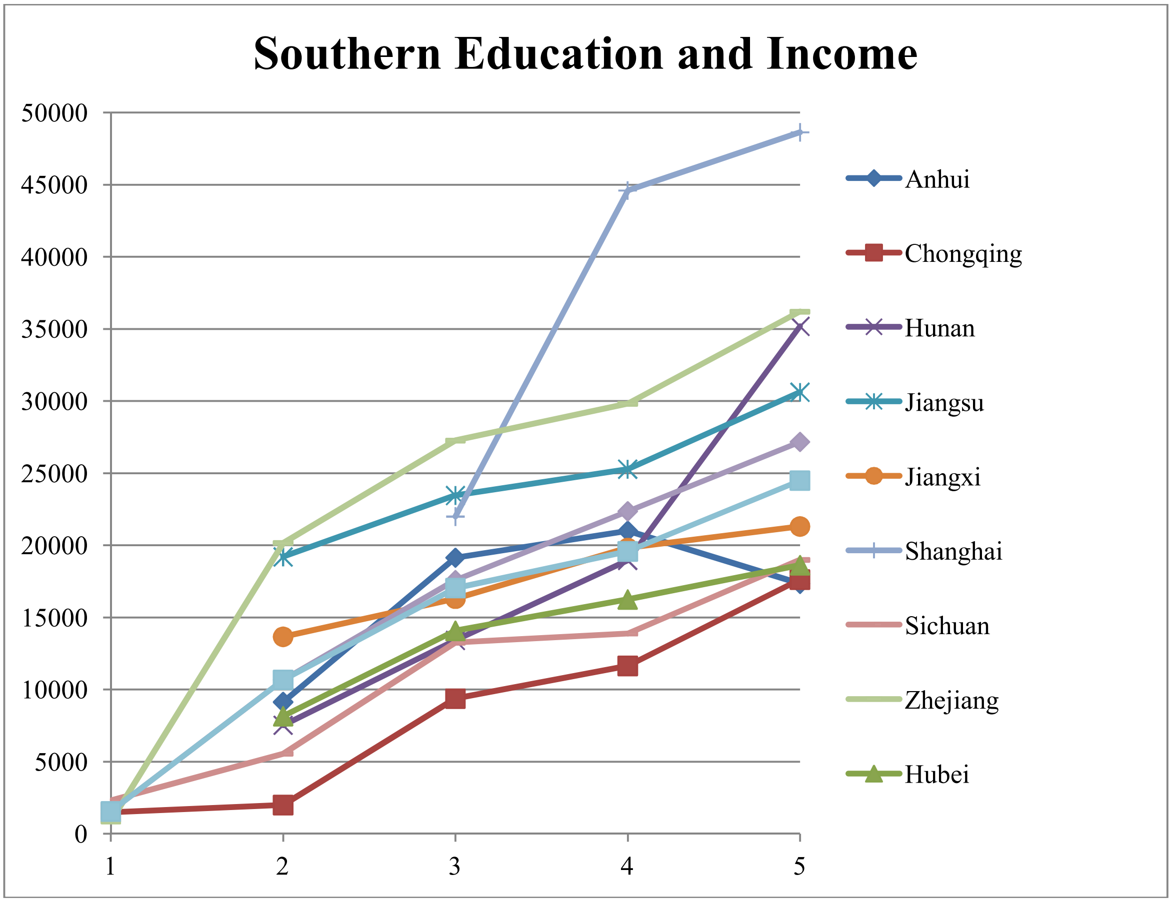

Figure 14: Southern income-education correlations

Linear trendlines were then evaluated for each province or city as shown below.

Table 21: Education and income correlations for Southern provinces

Anhui	y = 2646.8x +7395.7	$R^2 = 0.42$
Chongqing	y = 4190x - 4140	$R^2 = 0.95$
Hubei	y = 3356.7x + 2535.1	$R^2 = 0.94$
Hunan	y = 8851.9x - 12207	$R^2 = 0.92$
Jiangsu	y = 3607.1x +12014	$R^2 = 0.97$
Jiangxi	y = 2644.6x + 8521.6	$R^2 = 0.98$
Shanghai	y = 13318x - 14861	$R^2 = 0.86$
Sichuan	y = 4171.4x - 1713.8	$R^2 = 0.94$
Zhejiang	y = 8037.3x - 1247.8	$R^2 = 0.88$
Average Southern	y = 6292.7x - 3006.2	$R^2 = 0.98$
Average Southern without Shanghai	y = 5478.2x - 1765.4	$R^2 = 0.95$

4.2.2 Discussion

Evaluation of yearly incomes at different educational levels shows that while education has a huge impact on overall average income, values earned at the same educational level vary greatly amongst provinces. This result points to one purpose of migration – simply by moving to a different city or province, migrant workers may be able to greatly increase their yearly income even while staying at the same educational level. Conversely, if migrant workers are able to increase their educational level within their own city, this may allow them to increase their yearly incomes enough to reduce the felt need to migrate to another area to increase their income.

4.3 Regression Analysis of Factors Predicting Solid Fuel Use

Once equations have been determined which show the very clear link between increased education and increased income, the goal is to analyze how these and other factors affect solid and non-solid fuel use. This can be done by analyzing the data from the Tsinghua rural energy survey in R. In order to evaluate which factors most strongly predict solid fuel use by migrant workers, a generalized linear model (GLM) was applied. Then the 'stepAIC' function was used in R to analyze which factors (and in which combination) most strongly predicted solid fuel use for heating in Beijing, solid fuel use for cooking in Beijing, solid fuel use for heating in migrants' home towns, and solid fuel use for cooking in migrants' hometowns. StepAIC adds and drops different factors until it obtains a model that best predicts the output factor (R Documentation).

4.3.1 Overview of Data

While the Northern survey questions distinguished between cooking fuels and cooking equipment, heating fuels and heating equipment, the Southern survey questions only reveal cooking fuels and heating equipment. Still, use of solid and non-solid fuels can be distinguished for each of these cases. For analysis in R, cooking fuels and equipment and heating fuels and equipment were classified as solid/non-solid as follows:

Table 22: Cooking equipment solid/non-solid

Cooking Equipment	
SOLID	***NON-SOLID***
Coal stoves	LPG
Straw stoves	Digesters
	Electricity

Table 23: Cooking fuel: solid/non-solid

Cooking Fuel	
SOLID	***NON-SOLID***
Wood	Other
Straw	
Cornhusks	
Animal waste	

Table 24: Heating equipment: solid/non-solid

Heating Equipment	
SOLID	***NON-SOLID***
Kang	Air-conditioning
Boiler	Electricity

Table 25: Heating fuel: solid/non-solid

Heating Fuel	
SOLID	***NON-SOLID***
Coal	Electricity
Wood	
Straw	

The category of “other” poses a challenge, as it is unclear whether or not “other” would fall into the solid or non-solid fuel or equipment type. Given this uncertainty, it is decided to leave out “other” from the analysis, except in the one case of cooking fuel, where it is the only possibly non-solid choice for cooking fuel. In this case, it appears that families using cooking equipment of LPG, digesters, or electricity could be likely to select “other” as their cooking fuel (or have it selected for them by the person conducting the survey).

Because R cannot perform GLM analysis on blank values, the Tsinghua rural energy data set was culled to remove rows of data that contained blank values. This left responses that could be evaluated in R. Columns (questions) that did not seem applicable as contributing factors or had too many blank values in them were also removed from the data set. This greatly decreased the data set (to 455 data rows for the northern data and 676 for the southern data) but still left enough information to effectively conduct multiple linear regression.

Factors that were analyzed via GLM and stepAIC were:

Table 26: Factors analyzed to predict solid fuel use

Northern (2006)	Type of Response	Southern (2007)	Type of Response
Area heated	Continuous	Agricultural income	Continuous
Price of coal	Continuous	Land area	Continuous
Price of electricity	Continuous	Amount of fertilizer used	Continuous
Heating cost	Continuous	Temperature difference between the outside and inside	Continuous
Number of rooms	Continuous (1-5)	Amount spent on electricity (yuan per year)	Continuous
Number of bedrooms	Continuous (1-4)	Price of electricity	Continuous
Area of the house	Continuous	House height	Continuous
Wall thickness	Continuous	Area of the house	Continuous
Education level	1-5 Categorical	Year it was built	Continuous
Monthly income	Continuous	Wall thickness (cm)	Continuous
---		Roof thickness (cm)	Continuous
---		Education level	1-5 Categorical
---		Monthly income	Continuous

Overall solid fuel use was determined as whether a family was using at least one source of solid fuel for heating or cooking. Solid cooking equipment was evaluated as cooking equipment that would generally be used to burn solid fuels. For the northern survey data set solid cooking equipment types were coal stoves (煤炉) and another stove (柴灶), which is an older type of stove with a large round cooking pot (similar to a large wok) suspended over a place to burn biomass such as wood or straw. Heating equipment for the northern data set was defined as use of a kang (火炕)or an individual small boiler (自己安装的小锅炉) . The southern data set did not ask about cooking equipment, but solid heating equipment was defined as use of a stove (火

炉) or a kang (火炕). Overall solid fuel use for the southern data set was defined as use of either coal or biomass for cooking fuel (as the southern data set did not have data about heating fuel).

4.3.2 GLM Analysis of Northern and Southern Data

GLM and stepAIC analysis were performed in R in a similar manner to the analysis of the migrant survey data in the previous chapter. Each predictor was evaluated with all selected factors. After the stepAIC modeling was run, ANOVA Chi squared analysis was also performed. The coefficients and intercepts were then evaluated for the factors found in the StepAIC analysis.

Table 27: Top predictive factors of rural solid fuel use

Predictor		**Top Predictive Factor(s)**	**Step AIC Value**	**Intercept and Coefficients**	**Chi squared (value)**
Northern	Overall solid fuels	Number of bedrooms	AIC=54.67	-1.17*number of bedrooms + 6.63	No factors were significant
	Cooking solid fuels	Education + income + area heated + coal price + electricity price + area house	AIC=404.93	-0.026*education + (-1.5×10^{-5})*income + (-8.2×10^{-3})*area heated + (-3.9×10^{-3})*coal price + (3.02)*electricity price + (-1.2×10^{-3})*area house + 3.3	Price of coal (1.161e-05); Area heated (0.0001010); Income (0.001); Education (0.001); Price of electricity(0.0385)
	Heating solid fuels	Coal price + wall thickness	AIC=78.82	0.006*coal price + 0.059*wall thickness	Price of coal (0.0003)
Southern	Overall solid fuels	Number people + education + agricultural income + land area + temperature difference + amount	AIC=636.95	0.10*number people - 0.21*education + (-3.0×10^{-5})* agricultural income -.068*land area -0.15*temperature difference + (-4.0×10^{-4})amount spent	Temperature difference (1.553e-05); education (0.0002); agricultural income (0.003); land area (0.008); yearly income

		spent on electricity + house area + wall thickness + roof thickness		on electricity + (-2.8 x 10^{-3})house area + (-2.9 x 10^{-2})*wall thickness + (-1.8 x 10^{-2})*roof thickness + 4.27	(0.009); house area (0.01); amount spent on electricity per year (0.05)
	Cooking solid fuels	Number people + education + agricultural income + land area + fertilizer + temp difference + amount spent on electricity + house area + house year + roof thickness	AIC=705.7	(0.13)*number people + (-0.27)education + (-4.5 x 10^{-5})*agricultural income + (-0.13)*land area + (3.8 x 10^{-4})*fertilizer + (-0.13)*temp difference + (-5.7 x 10^{-4})*amount spent on electricity + (-1.8 x 10^{-3})*house area + (-0.013)*house year + roof thickness +29.4	Temperature difference (0.0001); education (3.168 e-05); agricultural income (0.0005); land area (0.001); yearly income (0.003); amount spent on electricity (0.007); amount of fertilizer used (0.03)
	Heating solid fuels	Temperature difference + amount spent on electricity + price of electricity + wall thickness	AIC=848.33	(-0.166)*temperature difference + (-6.0 x 10^{-4})*amount spent on electricity + (0.74)*price of electricity + (0.025)* wall thickness - 1.1	Temperature difference (2.862 e-06); price of electricity (0.003); amount spent on electricity per year (0.02)

4.3.3 GLM Analysis of Both Regions Together

Twelve factors were determined which could be examined for both the north and south locations. These factors are: location, education, income, area of home heated, coal price, electricity price, heating cost, amount spent on electricity each year, number of rooms, number of bedrooms, area of the house, and wall thickness. After examining these twelve factors, the top five predictive factors were determined. These factors were: location (north or south), education, income, home area, and amount spent on electricity.

These predictor values were evaluated for their effectiveness in predicting solid fuel use for cooking, solid fuel use for heating, and overall solid fuel use (use of solid fuel for either or both cooking and or heating. Results are shown in the table below.

Table 28: Significant predictive factors of rural fuel use

	Northern Top Predictive Factors	Southern Top Predictive Factors	Both Regions Together
Cooking	Education, income, area heated, electricity price, coal price	Education, income, agricultural income, land area, fertilizer used, temperature differences, yearly electricity expenses	1 Education 2 Income 3 Yearly electricity expenses 4 House area 5 Electricity price
Heating	Coal price	Temperature difference, yearly electricity expenses, electricity price	1 Location 2 Yearly electricity expenses 3 Electricity price
Total	Number of bedrooms	Education, income, agricultural income, land area, temperature difference, yearly electricity expenses, house area	1 Location 2 Education 3 Yearly electricity expenses 4 House area

Table 29: Predictors of solid fuel use for rural families

Predictor (for both regions)	Top Predictive Factor(s)	AIC Value	Intercept and Coefficients	P value
Overall solid fuel use	1 Location 2 Education 3 Yearly electricity expenses 4 House area	722	3.4*location -0.3*education -0.00069*spent on electricity -0.0019*house area +3.1	1 Location (~ 0) 2 Education (0.00015) 3 Yearly electricity expenses (0.0004) 4 House area (0.02)
Solid fuel use for cooking	1 Education 2 Income 3 Yearly	1171	-0.26*education -1.4×10^{-5}*income -5.5×10^{-4}*spent on	1 Education (~ 0) 2 Income (~ 0) 3 Yearly electricity

	electricity expenses 4 House area 5 Electricity price		electricity -0.58*price of electricity -0.001*house area +3.3	expenses (0.0009) 4 House area (0.0146) 5 Electricity price (0.01)
Solid fuel use for heating	1 Location 2 Yearly electricity expenses 3 Electricity price	961	4.9*location -0.00069*spent on electricity -0.58*price of electricity	1 Location (~ 0) 2 Yearly electricity expenses (0.0019) 3 Electricity price (0.03)

By using the equation for the logit function (see Section 3.4.1) the probability of overall solid fuel use can be calculated for all combined regions using the following formula:

$$P(of\ a\ given\ factor) = \frac{e^{(B0+B1\times xvals)}}{(1+e^{(B0+B1\times xvals)})}$$

which gives the following:

$$P(of\ overall\ solid\ fuel\ use\ for\ Northern\ and\ Southern\ China)$$
$$= \frac{e^{(3.4*location-0.3*education-0.00069*spent\ on\ electricity-0.0019*house\ area+3.1\ )}}{(1+e^{(3.4*location-0.3*education-0.00069*spent\ on\ electricity-0.0019*house\ area+3.1\ )})}$$

4.4 Discussion

From the GLM analysis of the Tsinghua rural energy survey data to evaluate the strength of various components in predicting solid fuel use for cooking, heating, and overall, several clear categories of strong predictors emerge. The four key factors in predicting rural solid fuel use are:

1. Location (whether a family is located in the north or south of China)
2. Education (highest educational level attained within the family)
3. Yearly electricity expenses (in yuan per year)

4. House area (size of the home)

By narrowing the factors down to these top four (location, education, yearly electricity expenses and house area) the relative significance of each factor can be examined, and the probability equations used to evaluated the use of solid fuel for cooking, heating, or overall use.

Some of the likely reasons why the top predictive factors are different for rural families as compared to migrant workers are because the heating burden for northern vs. southern regions is drastically different, survey questions for each survey (rural vs. migrant) were different, and the migrant population has a different lifestyle and income structure than people in rural areas. One factor (home area) that was significant for rural populations was not asked as a question in the migrant survey, and the types of fuel used "back home" and the number of years lived in Beijing area not relevant for the rural population.

In the two following chapters, rural correlations for income and education, along with calculations for probability of rural solid fuel use will be combined with results from analysis of the Beijing Migrant Workers Survey to create an agent-based model to predict solid fuel use for rural families and how that is predicted to change as migrant workers move from these rural areas into cities such as Beijing.

CHAPTER 5
AGENT-BASED MODEL: METHODS AND RESULTS

5 Agent-Based Model: Methods and Results

One goal of this research is to develop an agent-based model to predict solid fuel use in rural China and Beijing over the next 25 years. This model takes into account two of the major influences on fuel use, education and income, as well as a huge driving force within modern China: migration. The model was developed using data from the Tsinghua University rural energy survey, as well as a novel data set gathered in Summer 2011 on migration and energy use within Beijing. Work in developing this model is also influenced by more than two and a half years conducting field work in China – 14 months in 2007-2009, 16 months in 2009-2010, and six weeks of field work in summer 2011. The author is grateful to the University of Colorado, the National Science Foundation and the State Department Fulbright Program for their excellent support of her fieldwork, and is grateful to have had the experience to grow as an engineer by working overseas.

This section gives an overview of a previous World Health Organization model on solid fuel use, and explains what an agent-based model is and why Net Logo was chosen as a modeling toolkit. It then gives an overview of the agent-based model that has been developed. Results follow in the next chapter.

5.1 World Health Organization Model

One introduction to modeling for China is the model developed by the World Health Organization (WHO) for predicting solid fuel use for a number of countries, including China. The WHO has identified that solid fuel use is a risk factor for chronic obstructive pulmonary disease (COPD), acute respiratory infection (ALRI), and lung cancer (Smith, Mehta, &

Maeusezahl-Feuz, Chapter 18: Indoor air pollution from household use of solid fuels, 2005). They state that cooking and heating with solid fuels is the largest source of indoor air pollution (IAP) globally.

In their model, they divided the population into people that are and are not exposed to smoke from solid fuels, based on fuel use and ventilation. Fuel use was estimated at a national level, and binary classifications of solid vs. non-solid fuels were used as a surrogate for actual indoor air pollution (IAP) exposure, which clearly overlooks variability of exposure within each group.

The equation exposure used in this study and model was:

Household-equivalent solid-fuel exposed population =
(Population using solid fuel) X (Ventilation Factor)

Exposure to smoke from solid fuels was estimated by generating a regression model using:

- Independent, development related models (income, urbanization, etc)
- Ventilation factor (since the use of solid fuels does not always mean high exposure) based on qualitative measures of ventilation

The WHO study looked at 52 countries and 10 subregions (highly developed countries were assumed to have no solid fuel use) and compiled data of household fuel use. A statistical model was developed according to development parameters, and the model was used to predict use for countries without data. Ventilation factors were assigned based on qualitative evidence, and the theoretical minimum was no use of solid fuels.

For the China country model, annual residential fuel consumption was aggregated at the provincial level, and disaggregated by urban and rural areas. The average number of heating days per province was used to separate out heating and cooking, which removed an equivalent of 2kg of coal per heating day.

The remaining fuel was normalized to "useful energy" by using typical conversion efficiencies for each fuel-stove combination reported. The proportion of useful cooking energy for each fuel type, for each household, was taken to represent the number of households using that fuel. This process was repeated for each province and aggregated for a national total. Nearly 80% of the population was using solid fuels in 1996 (Smith, Mehta, & Maeusezahl-Feuz, Chapter 18: Indoor air pollution from household use of solid fuels, 2005).

The 'energy ladder' concept is shown here as the authors explain how people make the change to solid fuels as their incomes increase: "As a country develops, households gradually switch from using solid fuels to using cleaner liquid and/or gaseous fuels. Although the picture is often more complex at local and household levels, it is assumed here that this generally holds true over the long term on a sub-regional scale, a trend well-established by current, albeit cross-sectional, international comparisons. After a certain level of economic growth has been achieved, it is assumed that countries will shift away from cooking entirely with solid fuels. The use of solid fuel for heating may continue, however, especially in areas that are rich in coal and wood" (Smith, Mehta, & Maeusezahl-Feuz, Chapter 18: Indoor air pollution from household use of solid fuels, 2005, p. 1444).

For countries without fuel use data, a model to predict solid fuel use was developed that included as possibilites in part: adult female illiteracy, average annual growth rate, dummy variables for all subregions, electricity consumption per capita, fuel-wood production, population, fuel-wood production per capita, Gini coefficient, GNP per capita, petroleum use per capita, rural population and traditional fuel use (Smith, Mehta, & Maeusezahl-Feuz, Chapter 18: Indoor air pollution from household use of solid fuels, 2005, p. Table 18.4).

However, what the researchers found was that since GNP was such an accurate predictor of solid fuel use, they could go ahead and simply use GNP as a substitute for solid fuel use.

After reviewing the WHO model one research goal was to establish if it would be possible to create a better model to predict use of solid fuel (and thus, likelihood of these diseases) for rural China. Since the WHO model only used GNP and rough estimates, the goal was to establish a clearer way to determine what percentage of rural China is currently using solid fuels. This work was later expanded to look at how these percentages may change in the future with migration into the cities.

One limitation of the WHO study was that they found it difficult to sort out sources of solid fuel from those used for cooking versus heating. This is one of the benefits of using the Tsinghua survey data, as well as the novel Beijing survey data, since in both cases all respondents were asked separate questions about their cooking and heating fuels (and in some cases cooking and/or heating equipment).

5.2 Agent-Based Model Design

5.2.1 Selection of a Model Type

Originally, a research goal was to find a building modeling tool that would be able to model cost-effectiveness and environmental/health impacts for heating (windows, insulation, geothermal heat pumps, biomass pellets, coal, and radiant floors) and cooking (LPG, natural gas, biodigesters, biomass pellets, electricity, coal, wood, and gasification). For lighting the assumption was that all houses were connected to the grid, and for bathing solar hot water was considered as a renewable source.

One of the first steps in selecting a model was to go through the more than 300 building modeling tools listed in the National Renewable Energy Lab's (NREL) Building Energy

Software Tools Directory (Building Energy Software Tools Directory). This directory lists more than 300 modeling tools of different kinds, with a short summary of each and a link back to the original provider of the tool. After going through the modeling tools listed in the directory, tools that seemed promising were identified, based on their ability to model renewable energy sources, ability to model before/after retrofits, ability to model passive solar heating, the number of users, and ease of use.

While the original research focus included modeling the building environment, through the process of researching these models, thinking about the problem, and talking with other researchers, eventually the approach changed to focusing on modeling people and their behaviors (Watrous R. , 2011). Personal survey work in China in 2010 in the Beijing area, as well as in a rural area of Shanxi province, focused on energy choice, and how people make decisions about which type of energies they used, so it made sense to utilize a model which could incorporate these decision-making factors. Agent-based modeling has its roots in human behavior, so is a good fit to examine how factors like income and education play a role in how people in rural China and in the city decide which energy to use in their homes.

5.2.2 Agent-Based Modeling Overview

One aspect that makes predicting energy consumption so challenging is that it is based strongly on human behavior. Agent-based modeling (ABM) is a modeling technique that gives a set of individual agents a set of rules that govern their actions and decisions. Once these rules are established, the model can be run under various scenarios and the outputs compared (Watrous R. , 2011). Agent based modeling creates an 'artificial society', in which each person, each individual, is its own piece of software (Epstein).

ABM combines elements of game theory, emergence, and evolutionary programming. Agents act autonomously, are 'situated in place and time', and are 'intelligent and purposeful'. A main idea of ABM is that 'simple behavioral rules generate complex behavior'. Additionally, 'individual agents are typically characterized as boundedly rational, presumed to be acting in what they perceive as their own interests, such as reproduction, economic benefit, or social status, using heuristics or simple decision-making rules. ABM agents may experience "learning", adaptation, and reproduction"' (Wikipedia , 2010).

Most models have five components:

1. Numerous agents specified at various scales
2. Decision-making rules
3. Learning rules or adaptive processes
4. An interaction topology
5. A non-agent environment (Wikipedia , 2010).

One advantage of agent-based modeling is that it "can represent important phenomenon difficult to capture in conventional mathematical models". While traditional models assume that agents are rational and homogenous, these rules are 'relaxed' in ABM. Additionally: "an ABM can capture quantitative as well as qualitative factors and can also capture their complex interactions in an intuitive way (at agent level)" (Cheong, 2009).

Agent-based models have been used by the Brookings Institute, a leading Washington think tank, to model such dynamic systems as mitigating the infection rate of H1N1, understanding strategic learning, and genetic drift of new plant varieties. They explain that: "ABM rigorously incorporates rich and diverse human behaviors; facilitates interdisciplinary research and stakeholder participation; and provides an efficient test-bed for the simulation of public policy interventions" (Brookings Institute). All of these factors make ABM a great candidate for modeling human behavior-based rural development research.

Agent-based models have been used to model human-environment interactions in rural China, where fuelwood use has been shown to have negative impacts.

As the researchers explain: "By tracking 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 coevolve over time and space, resulting in macroscopic human and habitat dynamics. The results from the model may have value for understanding the roles of socioeconomic and demographic factors, for identifying particular areas of special concern, and for conservation policy making" (An, 2005).

ABM models to not need to be developed from scratch, but can be based on an existing toolkit. ABM toolkits frequently used are SWARM, Ascape, Repast, and MASON. Additional toolkits are Cormas, which has been used for rural development, or Janus, which allows organizational modeling (Wikipedia , 2010).

5.2.3 Selection of NetLogo as a Modeling Toolkit

After conducting initial research into possible modeling toolkits, Repast was originally selected as the best option. However, a fellow PhD student in Computer Science at the University of Colorado at Boulder, Rhonda Hoeningman, recommended use of Net Logo, which is more user-friendly, and has excellent documentation (Hoenigman, 2011). Rhonda also connected the author with Forrest Stonedahl, a graduate student at Northwestern University who is very experienced with NetLogo. Forrest concurred that NetLogo is easier to use than Repast and has a wide variety of example models (Stonedahl, 2011).

NetLogo was developed in 1999 by Uri Wilensky, and has been developed since then. The program is great for modeling intricate scenarios, and provides a large collection of example models for users to work with as they learn the system. NetLogo runs on JAVA, has a simple language structure, and a large vocabulary of built-in primitives. Models consist of mobile agents, or 'turtles', which move over stationary agents, or 'patches'. Models can be viewed in 2D or 3D, and the model creator can use such components as sliders, buttons, choosers, and monitors to give the user more modeling options (NetLogo).

5.3 Overview of Model Structure

The agent-based model has three main sources of data for inputs: the Tsinghua Rural Energy Survey, the Beijing Migrant Workers Energy Survey, and data from the China Statistical Yearbook. An overview of the use of data in the model follows.

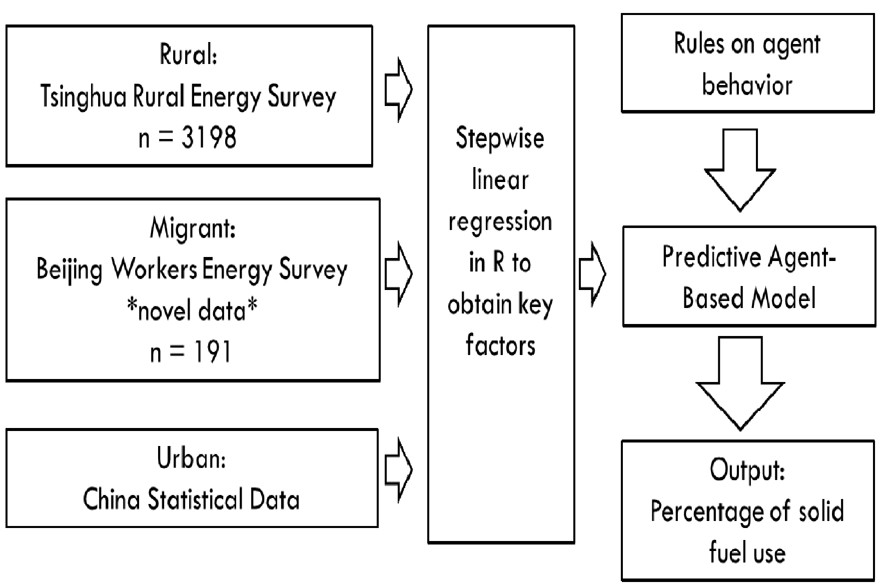

Figure 15: Overview of model flow

Probability of income based on educational level and region for rural families was developed, and the probability equation for solid fuel use by rural families and migrant workers based on top predictive factors was found in R. Rules and assumptions on agent behavior were developed and also incorporated into the model. The figure below shows an overview of the model flow.

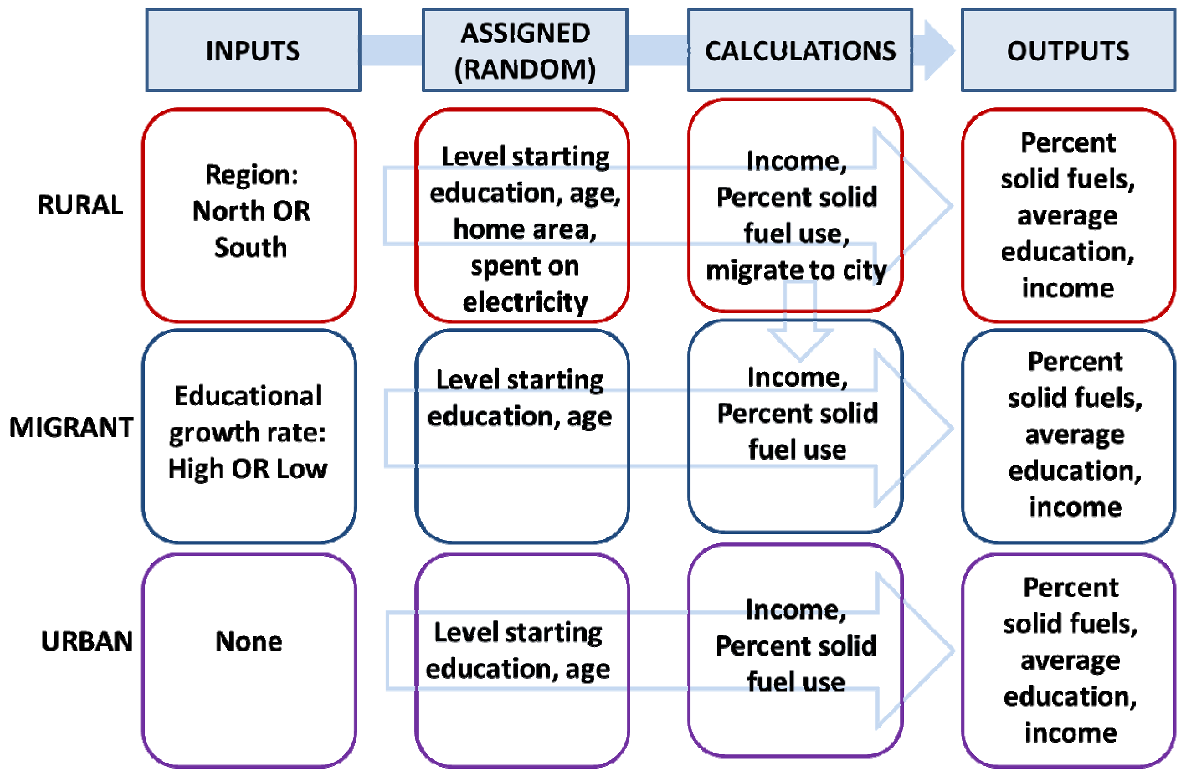

Figure 16: Model flow visualization

5.3.1 Model Steps

A more detailed explanation of the steps involved in creating the agent-based model and the inputs and outputs for each step is given below:

Step 1: Randomly create 100 agents (100 were used for ease in calculating percentages)

100 Agents

Step 2: Give each agent a location, based on random numbers between certain percentages (based on current data about China's demographics).

49-55% urban 9-16% migrant 29%-42% rural

Step 3: Give each agent an age. Agents in each area can be ages 0-74, while agents in the migrant group can be from age 15-55. This is based on the life expectancy for China, which is 73 years, and the expectation that migrants will not move and begin working before age 15 (World Bank, 2012).

49-55% urban Age 0-74 9-16% migrant Age 15-55 29%-42% rural Age 0-74

Step 4: Give each agent an education level. Elementary, middle school, high school and college education levels are assigned based on values shown in model details below.

Urban, age, education level Migrant, age, education level Rural, age, education level

Step 5: Based on location and education level, give each agent an income level (based on data from the Tsinghua rural energy survey and the novel migrant survey work in Beijing). Now each agent has the following:

- Location
- Age
- Education level
- Income

100 agents: each with specific location, age, education level and income

Step 6: Based on income and location, each agent's fuel type (probability solid or non-solid) can be calculated by using the Tsinghua rural energy survey data and data from the Beijing migrant workers energy survey (and GLM analysis in R). Now each agent has the following:

- Location
- Age
- Education level
- Income
- Probability of solid fuel use

100 agents: each with specific location, age, education level, income and probability of solid fuel use

Step 7: Run the model. Each tick of the model is equivalent to one year. In that year, the following things happen:

- All agents gain one year in age
- Agents above 75 die and a new agent (age 0) is created
- Agents ages 0-25 and less than level 5 in education gain one education level based on high or low education increase equations
- Agents gain education at a different rate based on their status (rural, urban, migrant)
- If agents gain education their income correspondingly increases
- Agents that are greater than age 25, less than 35 years old and have an education level less than 5 will change their status from rural to migrant

Step 8: Each time the model is run, total percentages of solid versus non-solid fuel use for each area (urban, migrant and rural) after 25 years are calculated.

5.3.2 Model Procedure

The main procedure each tick (year) of the model runs through is:

1. Establish three different breeds of agents: rural, urban, and migrant
2. Set up the patches (area the agents move on) and turtles (agents in NetLogo are called turtles)
3. Establish the cycle the model will run through each tick (each year is one tick). Each year each agent will go through the following process.
    a. Earn income
    b. Get older
    c. Increase educational level (if they are at a certain age)
    d. Calculate the percentage of solid fuel being used
    e. Possibly migrate to the city
    f. Have new agents born if old ones die
    g. Plot the results each consecutive year
4. Go through the rules (equations) for income, education and solid fuel use for each breed of turtle (rural, urban, migrant)
5. Plot the results each year

5.4 Model Inputs and Assumptions

5.4.1 Model Inputs: Region and Education Rate

The two sets of inputs which the model user can choose are the region (either north or south) and the rate of education increase. Provinces were grouped into north and south, as this location distinction was a significant factor in predicting rural fuel use (and the Tsinghua surveys were conducted in different years in these different regions).

The two levels “high” and “low” of education rates of increase were calculated based on in the “high” scenario, assuming an agent completes college by age 23. In the second case, the agent is assumed to only attain a middle school education (at age 20, they only have a middle school education). Ages for each educational level are:

Table 30: Low and high educational rates

Level	Age - High Rate	Age - Low Rate
None	5	7
Elementary	12	14
Middle school	15	20
High school	18	-
College	23	-

The high and low rate equations are given below.

The rural population is assumed to have the lower rate of education, and the user can choose which rate the migrant population experiences.

5.4.2 Model Assumptions: Education and Migration

Education levels were set to be dependent on the age of the rural agent, with some randomness. Rural agents increase their educational level based on the “low” educational rate.

Table 31: Rural and migrant education levels

Rural Age	Rural and Migrant Education Levels
< 18	Primary school
>18	9% chance of being at college level, 39% chance of being at high school level 49 % chance of being at middle school level

Education levels were also set to be dependent on the age of the migrant agent, with some randomness. Migrant workers in the model increase their educational level based on whether "high" or "low" is selected for their education rate. Migrant workers and rural people have the same randomly assigned possibilities of going to high school and college.

Urban education levels were set to be dependent on the age of the urban agent. Urban residents in the model increase their educational level at a value of 0.10 each year (levels range from 1-5) and their probabilities of attending school are shown below.

Table 32: Urban education levels

Urban Age	Urban Education Levels
< 18	Primary school
>18	19% chance of being at college level, 49% chance of being at high school level 29 % chance of being at middle school level

It is expected that that urban residents will have much higher education rates than their migrant or rural counterparts and this is reflected in these values.

Migrant workers are programmed to migrate to the city if they are greater than 25, less than 35, and their educational level is less than 5 (college). This is a broad assumption based on the extremely high levels of migrant workers currently and predicted to be leaving their hometowns.

5.4.3 Model Calculations: Income

Estimates of how rural income level is dependent on education (and region) were calculated from the Tsinghua Rural Energy Survey data set as explained in Chapter 4. The equations used in the model are:

$$Rural\ Income\ (north) = 3345.5 * education + 1437.8$$

$$Rural\ Income\ (south) = 6292.7 * education - 3006.2$$

Migrant income and its dependence on education level is explained in Chapter 3. The equation used in the model is:

$$Migrant\ Income\ (Beijing) = 6734.50 * education + 12818$$

Urban income was set to be the average yearly income for Beijing in 2010, 65,683 rmb (People's Daily, 2011).

An economic inflation rate of 6% was assumed for each population and factored into the model equations (Trading Economics).

5.4.4 Model Calculations: Solid Fuel Use

Percentage of solid fuel use for rural agents is determined using the probability equation determined in R:

$$P(of\ overall\ solid\ fuel\ use\ for\ Northern\ and\ Southern\ China) = \frac{e^{(3.4*location-0.3*education-0.00069*spent\ on\ electricity-0.0019*house\ area+3.1\ )}}{(1+e^{(3.4*location-0.3*education-0.00069*spent\ on\ electricity-0.0019*house\ area+3.1\ )})}$$

Location (north or south) is chosen by the model user. Starting education levels are randomly assigned based on assumptions shown below and education rate is the “low” rate. Amount spent on electricity is randomly assigned by the model to be between 4800 and 14 rmb per year (this is the range of values provided by the Tsinghua data). Home area is also randomly assigned by the model to be between 620 and 8 square meters (again the range of values provided by the Tsinghua data).

Percentage of solid fuel use for migrant agents is determined using the probability equation determined in R from the Beijing data set:

$$P\ (Solid\ fuel\ use\ by\ migrant\ workers) =$$

$$\frac{e^{(30*solid\ cooking\ at\ home+29*solid\ heating\ at\ home-0.9*years\ in\ Beijing-0.2)}}{1+e^{(30*solid\ cooking\ at\ home+29*solid\ heating\ at\ home-0.9*years\ in\ Beijing-0.2)}}$$

Solid cooking at home and solid heating at home are both randomly assigned by the model (per migrant agent) to be a random decimal value between 0 and less than 1.0. The number of years in Beijing is calculated by subtracting a random number between 15 and less than 25 from a migrant workers' age. For example, if the random number is 17, and their age is 40, their "years in Beijing" value would be 23. Urban residents are assumed to use 100% non-solid fuels if they have an education above a level 1 (above the base level of no education). This means that urban residents with no formal education are expected to use solid fuels but those with a primary or above level of education are expected to use non-solid fuels.

5.4.5 Model Assumptions

The following table gives an overview of model assumptions and the basis for them.

Table 33: Model assumptions

Model Assumptions	Basis
Percent population rural, urban, migrant	Based on current demographics
Age between 0-74	Based on average Chinese life expectancy (starting migrant ages are lower, assuming older migrant workers may return to their home town)
Electricity spent per year	Random between rural ranges provided by Tsinghua data set
Home area	Random between rural ranges provided by Tsinghua data set
Starting educational values	Based on China statistical data
Starting income (Beijing)	Based on published Chinese data
High and low educational rates	Based on calculations of age and average income (going to college versus only completing middle school)
Cooking and heating with solid fuels in home town	Set randomly between 0 (no solid fuels) and 1 (at least one type of solid fuel) for cooking and heating separately
Migration rate	Rural people with ages greater than 25 and less than 35 and an education level less than 5 are expected to migrate to the city

Rural and migrant average income levels, as well as rural and migrant percentage of solid fuel use, are calculated from the Tsinghua and Beijing data sets, respectively.

5.4.6 Evaluation of Colinearity

For both the migrant and rural populations, colinearity for the top identified factor was examined. No strong interdependencies were found for any factors in the migrant or rural sets, although there may exist a connection between education and *average* income level. These results differ from other dependencies found, for example between education and income, but those were found by examining difference between averages, not by graphing the entire data. Tables and graphs for the migrant population are shown below. All income levels are reported in rmb.

In each colinearity table, a (-) sign indicates no interdependency and a (+) sign indicates interdependency.

Table 34: Colinearity for migrant population

	Income	Education	Heating back home	Cooking back home	Years in Beijing
Income		-	-	-	-
Education	-		-	-	-
Heating back home	-	-		-	-
Cooking back home	-	-	-		-
Years in Beijing	-	-	-	-	

Graphs for the migrant population follow. Some dependencies that we would expect to see (for example, income and education) are not seen here – likely due to the spread of the data. An examination of the averages may result in more clearly observing dependencies.

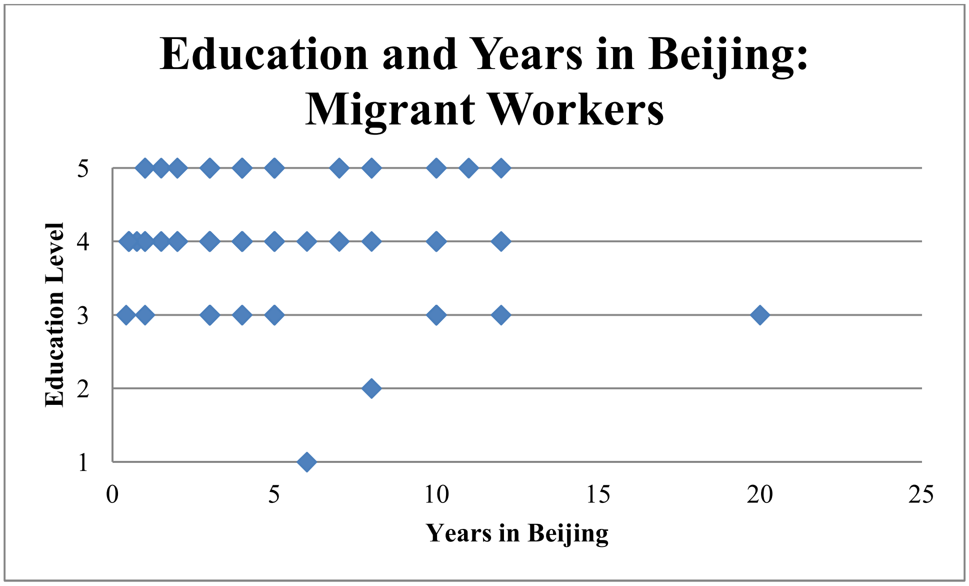

Figure 17: Education and years in Beijing: migrant workers

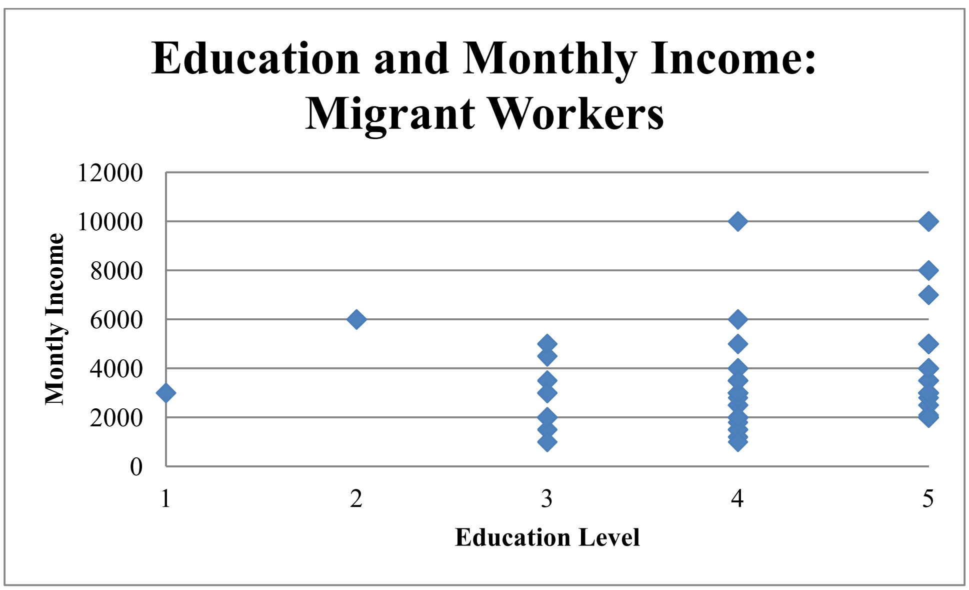

Figure 18: Education and monthly income: migrant workers

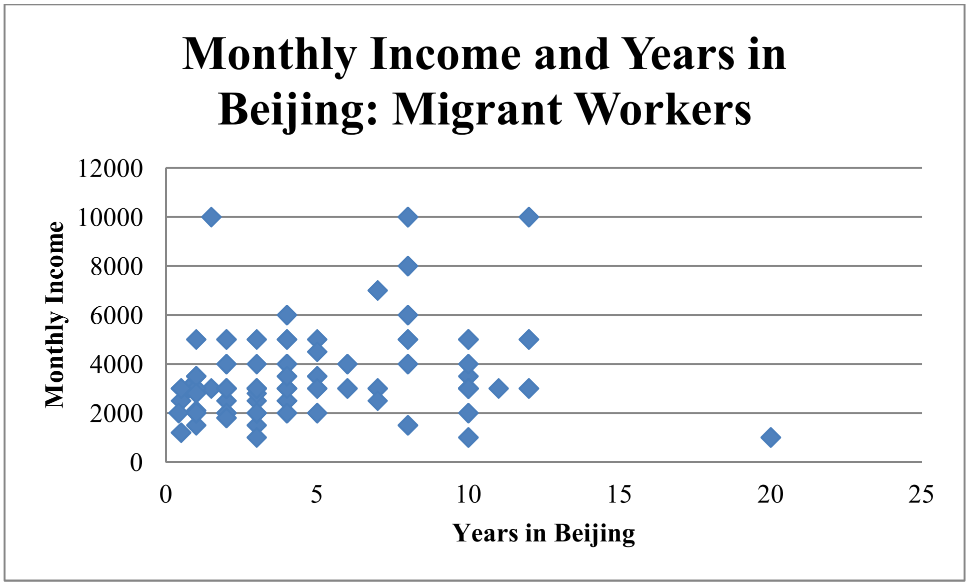

Figure 19: Monthly income and years in Beijing: migrant workers

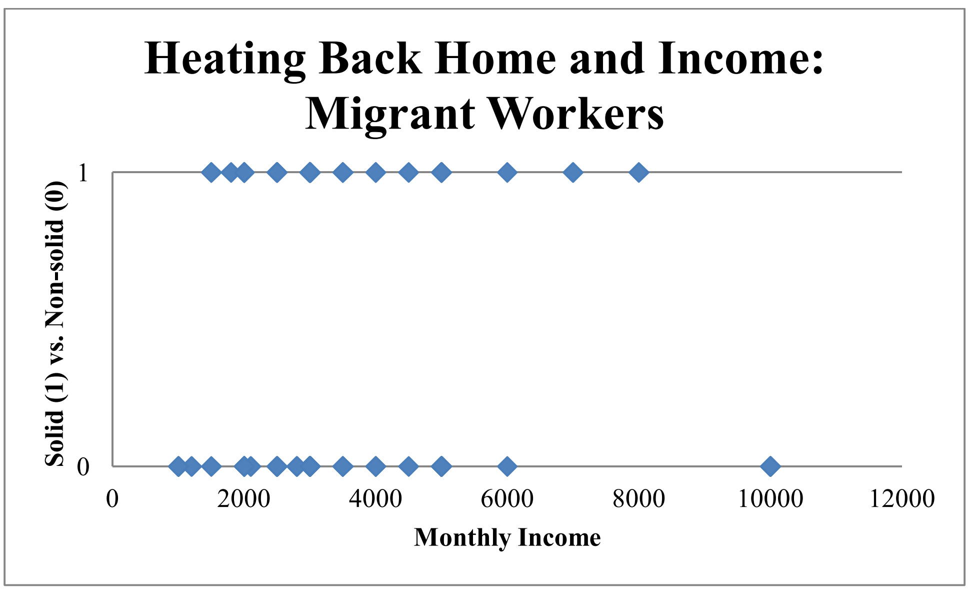

Figure 20: Heating back home and income: migrant workers

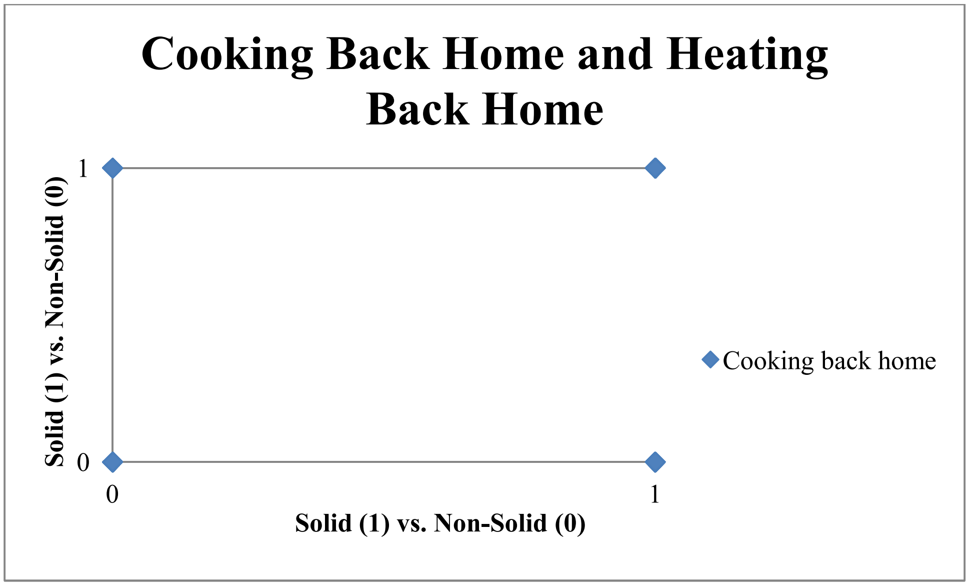

Figure 21: Cooking back home and heating back home: migrant workers

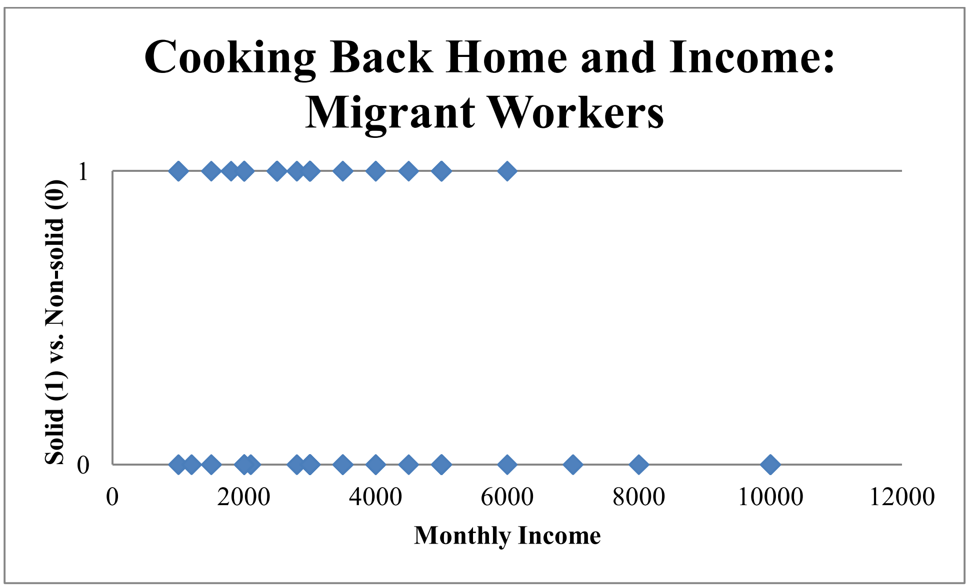

Figure 22: Cooking back home and income: migrant workers

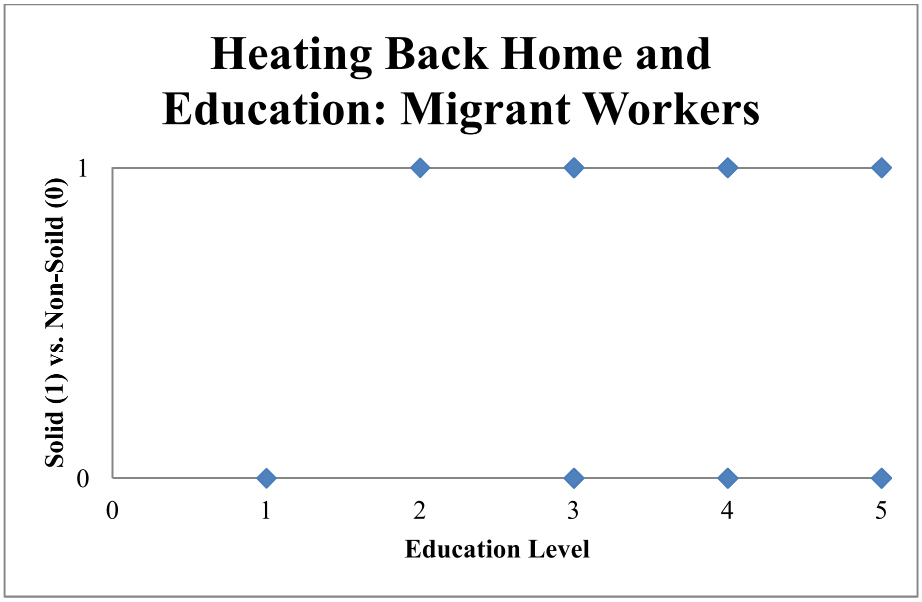

Figure 23: Heating back home and education: migrant workers

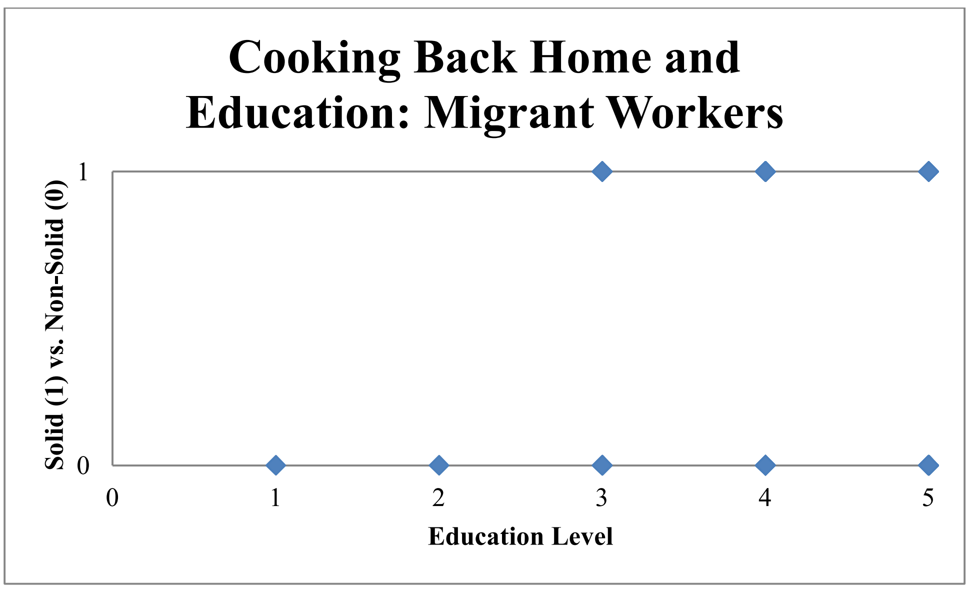

Figure 24: Cooking back home and education: migrant workers

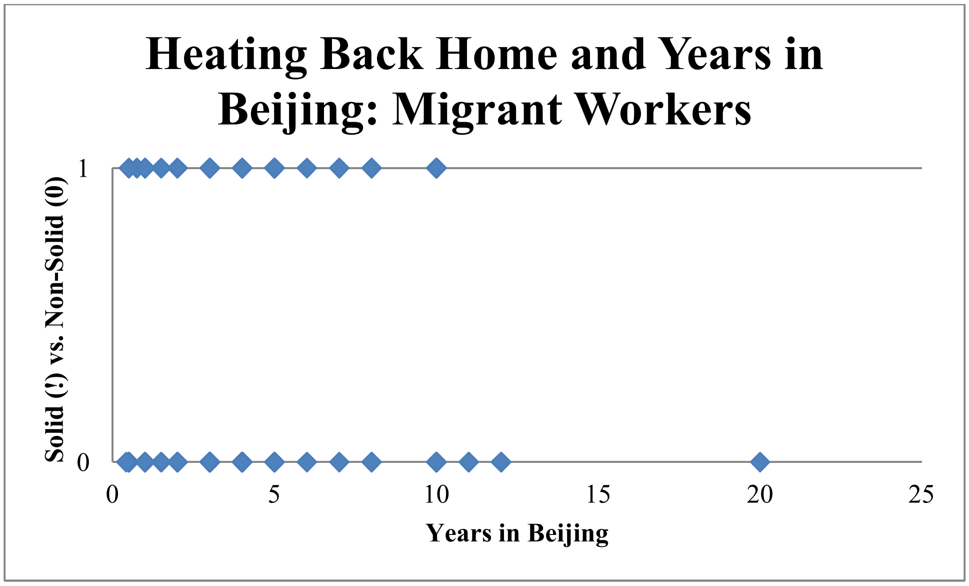

Figure 25: Heating back home and years in Beijing: migrant workers

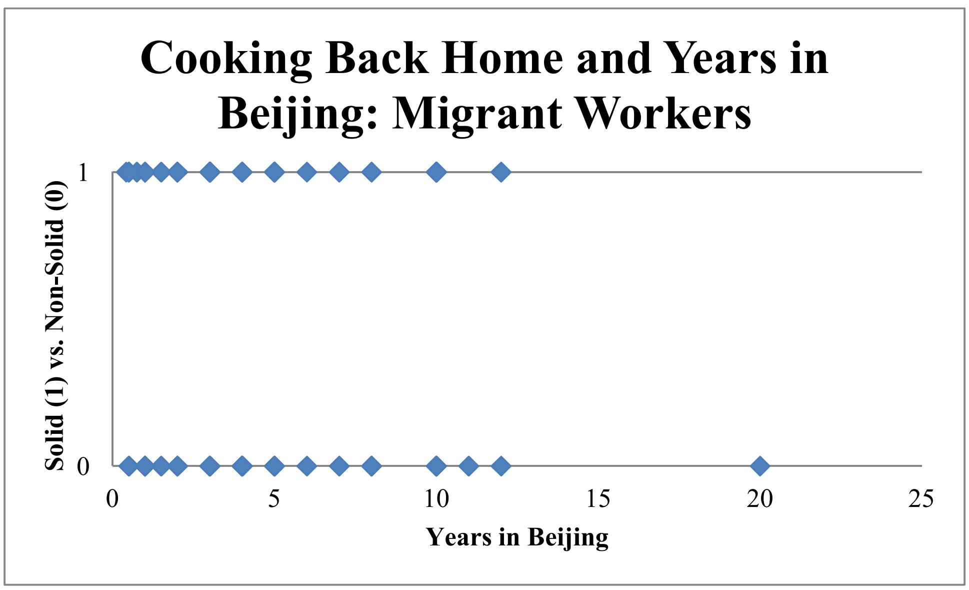

Figure 26: Cooking back home and years in Beijing: migrant workers

The same approach was applied to the top identified factors for the rural data set (a much larger data set) and again, no clear dependencies were found. Table and graphs follow below.

Table 35: Colinearity for rural population

	Income	Education	Location	Home area	Amount spent on electricity
Income		-	-	-	-
Education	-		-	-	-
Location	-	-		-	-
Home area	-	-	-		-
Amount spent on electricity	-	-	-	-	

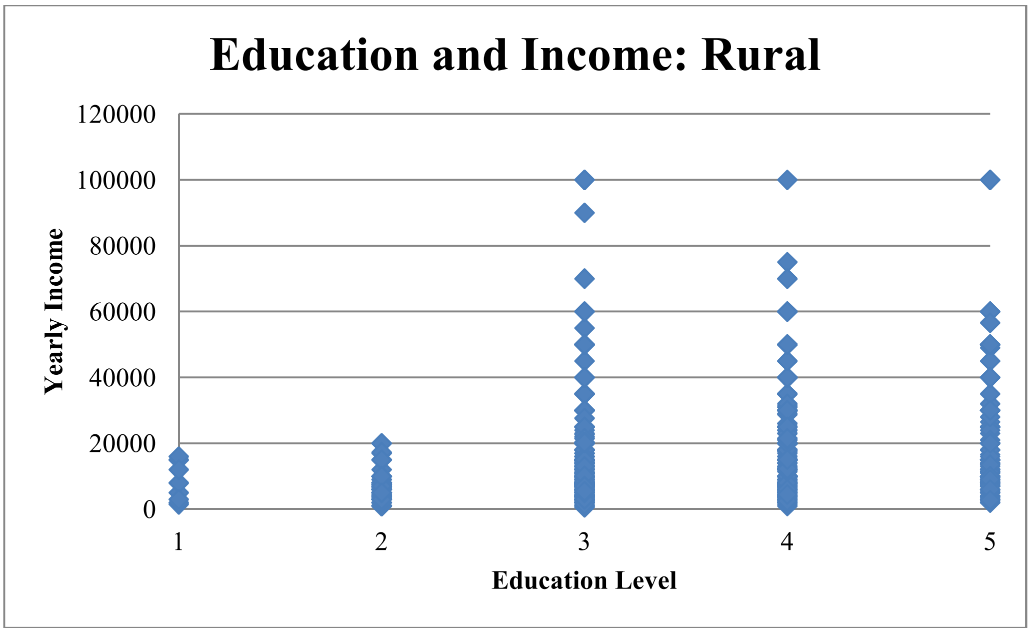

Figure 27: Education and income: rural

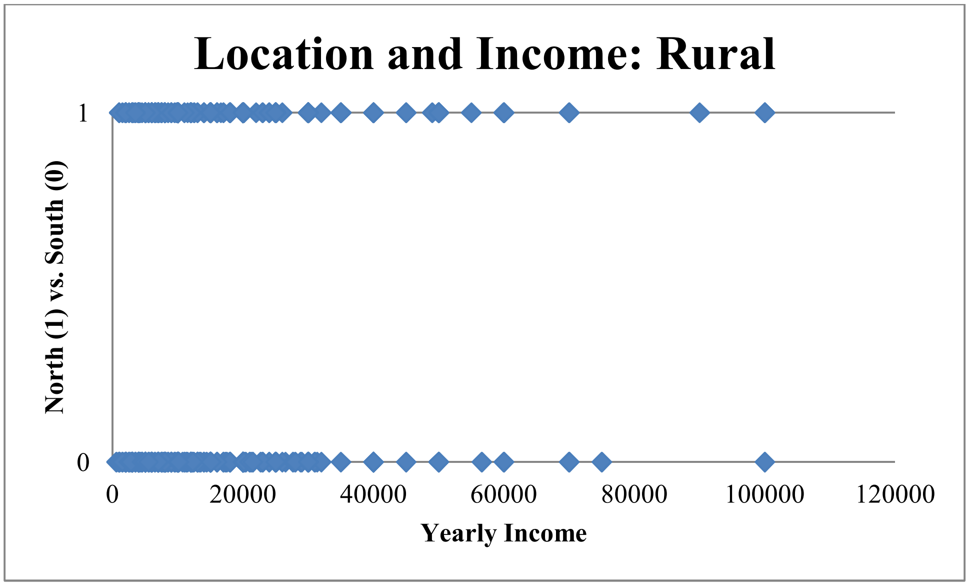

Figure 28: Location and income: rural

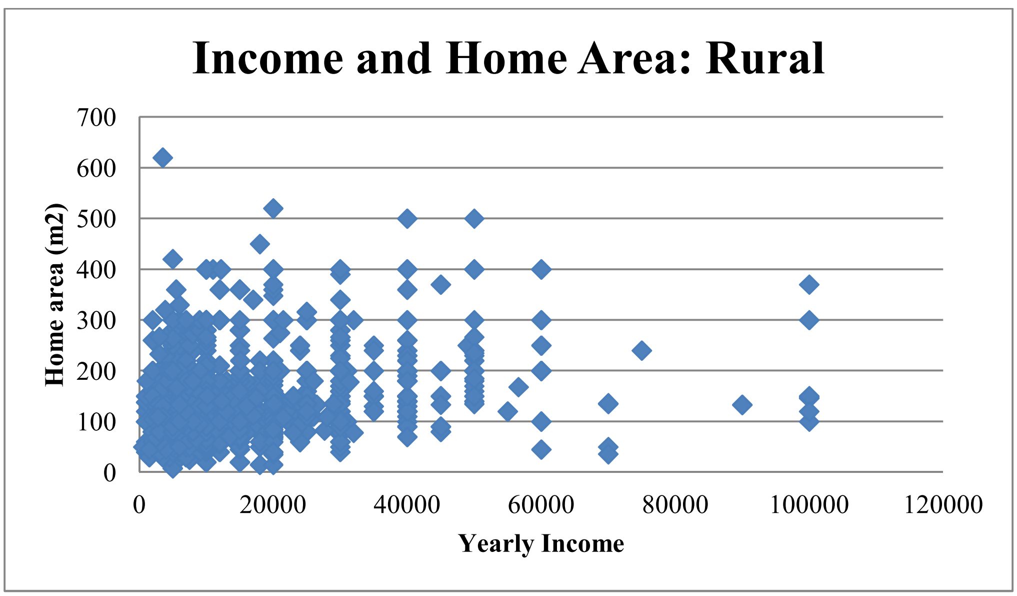

Figure 29: Income and home area: rural

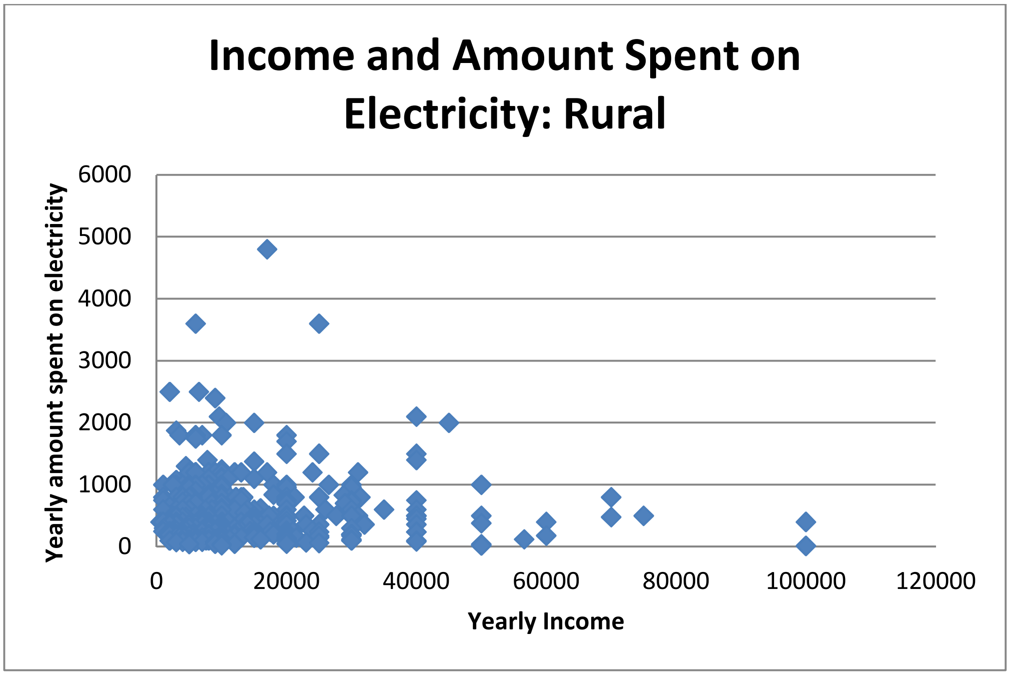

Figure 30: Income and amount spent on electricity: rural

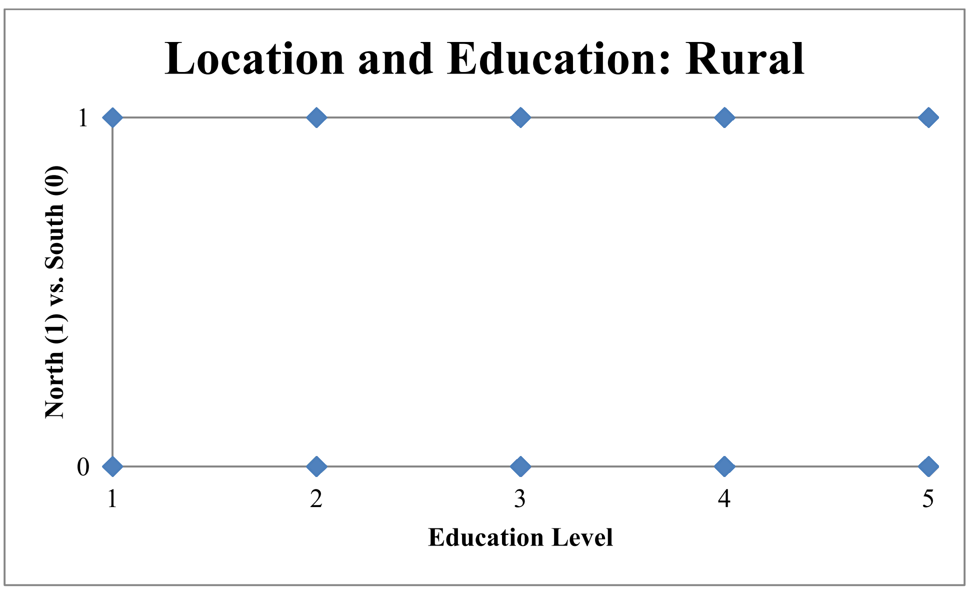

Figure 31: Location and education: rural

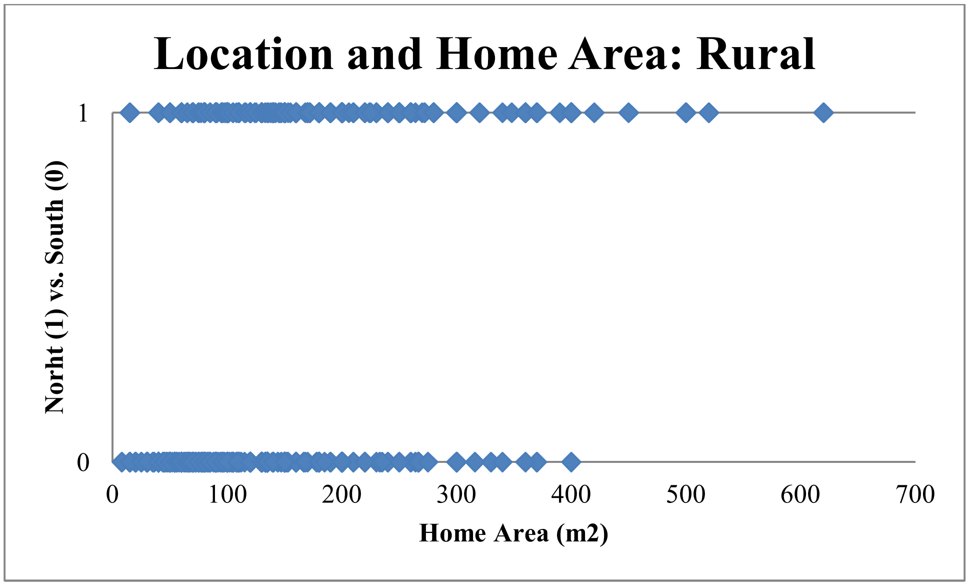

Figure 32: Location and home area: rural

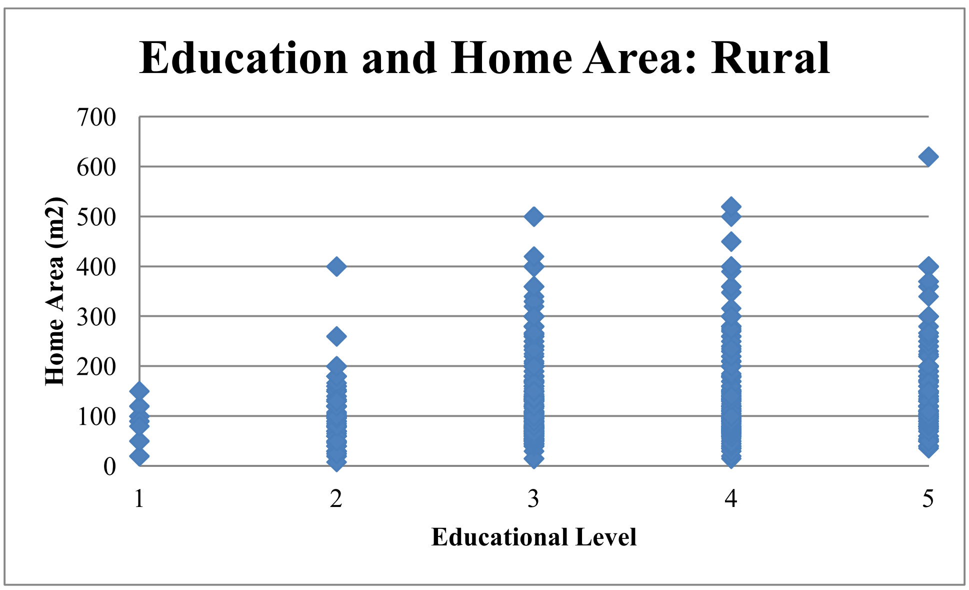

Figure 33: Education and home area: rural

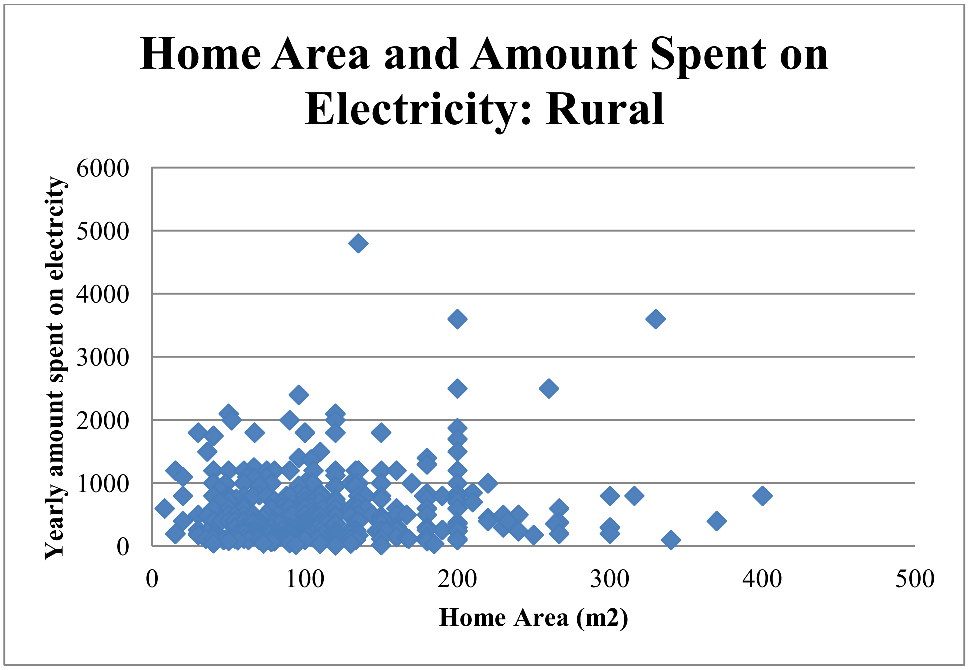

Figure 34: Home area and amount spent on electricity: rural

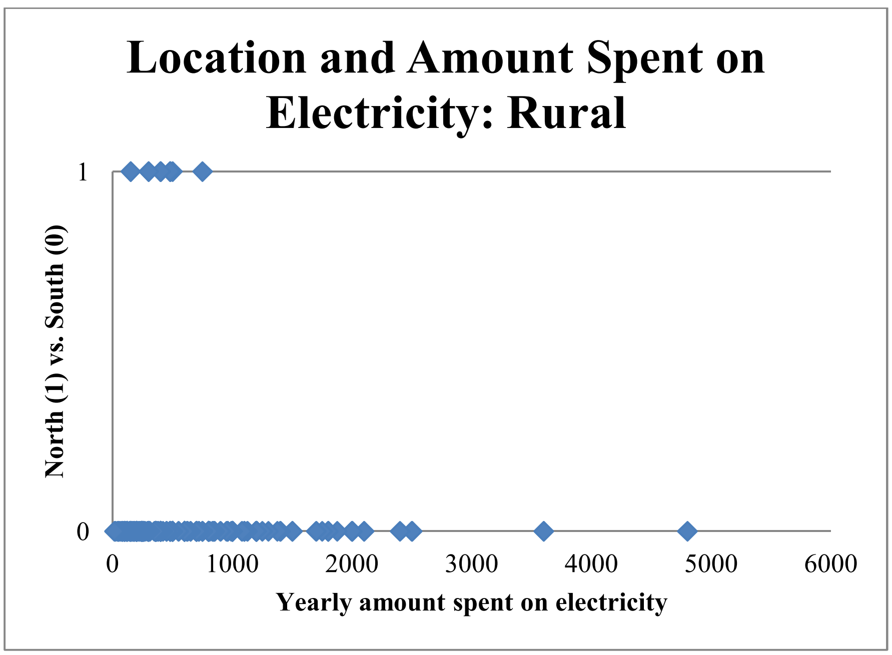

Figure 35: Location and amount spent on electricity: rural

This graph (location and amount spent on electricity) is misleading because for the Northern area, many respondents for some reason left this question blank. The average yearly cost for southern areas was 391 rmb per year. For northern areas the reported cost was 586 rmb per year, but only 11 respondents responded to this question, so this difference in cost between regions may not be significant.

5.5 Agent Based Model Display

5.5.1 Overall Display

Use of NetLogo to create an agent-based model provides ability to create a clear user interface. This can include such features as plots, sliders, and output boxes. The model interface is shown below. The user can choose which region and educational level they would like to investigate by selecting "High" or "Low" on the green "Learning" chooser box, and "North" or "South" for the region on the green "Province" box. Two plots provide a visual representation of average yearly income for each population as well as average percentage of solid fuels for each population. The calculations for average percentage of solid fuels for migrant and rural populations are the average of all the migrant or rural agents' percentage of solid fuel use, respectively. The average percentage of solid fuel use for urban agents is the percentage of the urban population with an education level above one (assumed to be using non-solid fuels).

Several different output boxes show numeric values for the year; average age of the total population; the ratio of urban to rural income; the ratio of urban to migrant income; and the percent population, percent solid fuel use, average income, and average education levels for each of the three populations – urban, rural and migrant.

The colored display shows different populations moving on a yellow background. Starting colors for each population type are blue for rural, red for urban, and orange for migrant. Migrant workers have a greater range of movement than the other populations, so you can see them moving further. As each agent changes to using primarily non-solid fuels, their color changes from their original color to green. Urban agents change their color to green when their education level is above a level one. Rural agents change color to green when their percent solid fuel use is less than twenty percent. Migrant agents change their color to green when their percent solid fuel use is less than fifteen percent. Output boxes give the "Total percentage solid fuels" and "Total percentage non-solid fuels" which are actually the percentages of the 100 agents which have changed colors to green, indicating that they are using cleaner energy.

A screenshot of the model shows the user interface with plots and output values.

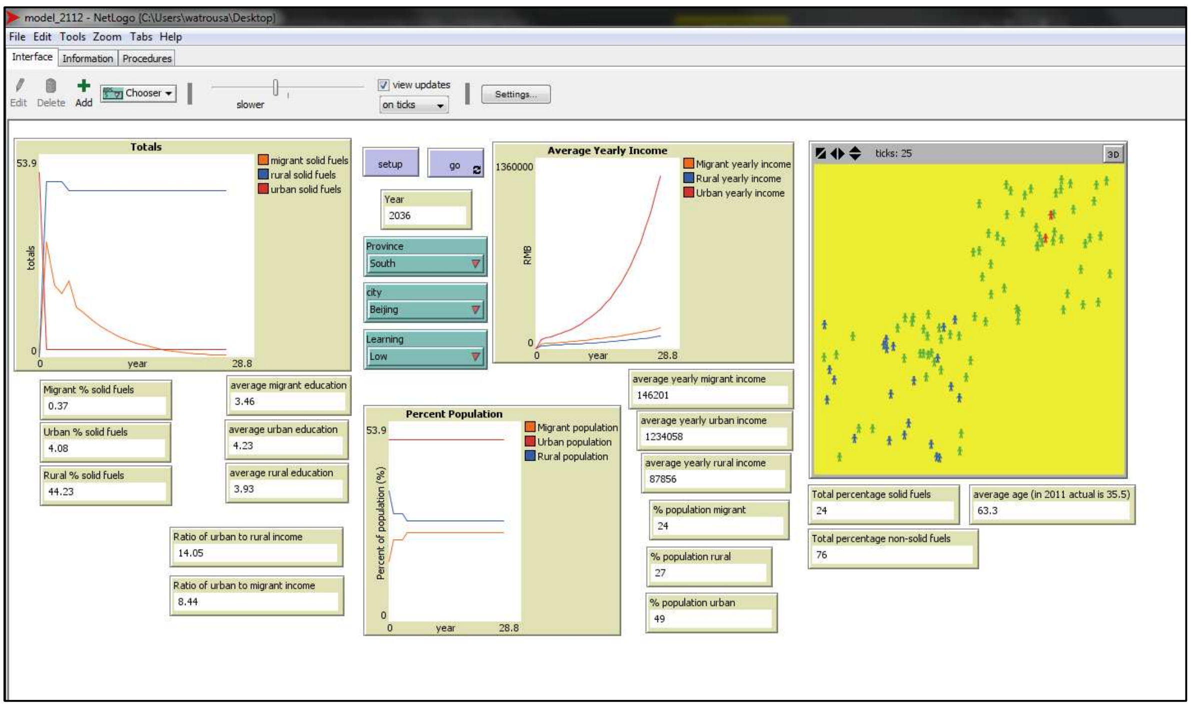

Figure 36: Model user interface

A summary of output values, plots and views follows.

Table 36: Agent-based model outputs

Model Outputs		
Output Values	Plots	View of Agents Moving
Year	*Total percentage of agents which have switched colors to green*[15] *(rural, migrant, urban)*	*Color view of different agents moving from rural to urban area*
Percentage of solid fuels (rural, migrant, urban)	*Average yearly income (rural, migrant, urban)*	
Average education level	*Percent population (rural, migrant,*	

15 Indicating that they are primarily using non-solid fuels.

(rural, migrant, urban)	*urban)*	
Average yearly income (rural, migrant, urban)		
Percentage of population (rural, migrant, urban)		
Average age		
Ratio of urban to rural income		
Ratio of urban to migrant income		

5.6 Agent-Based Model Validation

As explained previously, validation of an agent-based model contains 3 components – verification, validation, and sensitivity analysis. Sensitivity analysis is covered in the next section, and verification and validation are covered here.

The first step, verification, makes sure that the program is basically performing the way we want it to, that there are no bugs in the program, and that the results we're seeing make sense overall. Verification for this particular model was performed by assessing the following outputs:

Table 37: Verification steps

Verification Step	Outcome	**Notes**
No bugs in the program	√	NetLogo is helpful in this respect as it won't run without bugs
Average yearly incomes make sense graphically	√	Urban-migrant-rural income gaps are observed
Total percentage solid fuels makes sense graphically	√	Difference in fuel use among populations is observed
Different outcomes produced for high versus low learning inputs	√	More solid fuels used for low education rate
Different outcomes produced for North versus South rural regions	√	More solid fuel use observed in the North which makes sense given the greater heating burden
Average educational levels observed	√	Average migrant educational levels match with Beijing data set, urban education rate generally slightly higher, rural level is lower than or about the same as migrant
Percent population change	√	Percent of population that is migrant workers changes up to about 22-26 percent as expected based on predicted migration patterns

Once verification was successfully performed, validation via rural income was conducted. Because China does not provide clear data on percentage of solid fuel use, external validation in terms of other variables is challenging. The selected method is to "back-predict" average rural income for the past several decades in the model, and use this to compare with published average Chinese rural incomes. Rather than running the model forward from 2012 to 2027, we can instead examine values from 1999 to 2009, which allows comparison of model rural values with published China Statistical Yearbook values (National Bureau of Statistics of China).

Urban incomes cannot be easily validated due to the extreme growth rate of China's economy over the past few years. Since the model only includes a 6% rate of inflation, it does not account for the double-digit growth rates of the past several years. However, urban income rates (for Beijing) were also compared from 1999 to 2009.

Because the China Statistical Yearbook reports per-capita income, and the Tsinghua survey asked for family income, both the urban and rural yearly income values from the Statistical Yearbook were multiplied by two for a more accurate comparison. The learning rate was set on high for these comparisons. A more detailed analysis of learning rate and region on income and fuel use follows in the next section.

The model was run for each year from 1999-2009. Three runs for each year for each region were performed and average results for each region and the overall rural area were calculated. Yearly urban income (for Beijing) was also reported. Results are shown in the table below.

Table 38: Agent-based model outputs for 1999 to 2009

AREA	RUN	YEAR										
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Income North	1	6026	6180	6466	7181	7618	8079	8570	8851	9221	10324	10561
	2	5389	6123	6501	7238	7796	7939	8162	9178	10110	9500	10168
	3	5762	6113	6803	7096	7370	8221	8903	9039	9437	10324	10204
Average North		5725.67	6138.67	6590.00	7171.67	7594.67	8079.67	8545.00	9022.67	9589.33	10049.33	10311.00
Income South	1	8257	8613	9451	9847	10723	12538	11260	13059	14572	15198	15831
	2	8611	8724	9689	10117	10461	11472	11618	13622	15071	14124	11949
	3	8370	9093	10001	10461	11388	10969	12444	13415	15625	14603	14366
Average South		8412.67	8810.00	9713.67	10141.67	10857.33	11659.67	11774.00	13365.33	15089.33	14641.67	14048.67
Average Rural		7069.17	7474.33	8151.83	8656.67	9226.00	9869.67	10159.50	11194.00	12339.33	12345.50	12179.83
Urban Income		29052	30795	32642	34601	36677	38878	41210	43683	46304	49082	52027

Percent differences between the model and reported values were calculated and are presented in the table below. There are several likely reasons for the differences between data from the yearbook and from the model. Firstly, survey respondents commonly over or under report data, which skews the results. Secondly, the difference between per-capita income and family income may be much greater than just a factor of two – with an extended family living together in a rural area, the actual multiplier for per-capita to family income could be high, and could differ with each rural family. All of these factors make predicting and comparing rural incomes challenging.

Table 39: Percent difference between model and reported incomes

Data Comparison	YEAR										
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Reported Rural * 2	4420.6	4506.8	4732.8	4951.2	5244.4	5872.8	6509.8	7174	8280.8	9521.2	10306.4
Reported Urban *2	11708	12560	13719.2	15405.6	16944.4	18843.2	20986	23519	27571.6	31561.6	34349.4
Model Rural	7069.17	7474.33	8151.83	8656.67	9226.00	9869.67	10159.50	11194.00	12339.33	12345.50	12179.83
Model Urban	29052	30795	32642	34601	36677	38878	41210	43683	46304	49082	52027
% Difference Rural	37.47	39.70	41.94	42.80	43.16	40.50	35.92	35.91	32.89	22.88	15.38
% Difference Urban	59.70	59.21	57.97	55.48	53.80	51.53	49.08	46.16	40.46	35.70	33.98

As can be seen from the table above, rural incomes differ from reported by 15-43 percent and urban incomes differ from reported by 34-60 percent. A decrease in percent difference for rural income in year 2008 and 2009 may reflect the recent changes that are taking place demographically.

5.6.1 Validation for Extreme Cases

As mentioned above, one effective way to validate a model is by considering the extreme cases. This can be done for the migrant population by considering four separate cases:

1. Solid fuel used for both cooking and heating at home
2. Solid fuel used for neither heating or cooking at home
3. Solid fuel used for heating but not cooking
4. Solid fuel used for cooking but not heating

For each of these cases we then consider the three extremes of migrant workers living in Beijing for one year, 65 years or 100 years. This gives twelve possible extreme cases, as outlined in the table below. In each of the twelve cases, the model inputs for percentage of solid fuel use (type of fuel used at home, number of years in Beijing) were changed within directly. The number of years the model ran was also changed (to one, 65, or 100 years depending on the case) from the usual 25 year run. For examining extreme cases for the migrant agents, the region was set to South and the learning rate to high. The results of the five model runs for each migrant case are shown below along with average results and standard deviations.

Table 40: Results of model runs for extreme cases: migrant agents

		Model Run						
Case	**Number of years**	**1**	**2**	**3**	**4**	**5**	**Average**	**Standard Deviation**
1 (solid fuel used for both cooking and heating at home)	1	74.99	81.24	83.33	95.00	80.26	82.96	7.40
	65	34.47	37.17	31.16	43.08	31.59	35.49	4.88
	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 (solid fuel used for neither cooking or heating at	1	24.97	24.97	24.97	24.97	24.97	24.97	0.00
	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00

home)								
3 (solid fuel used for cooking at home)	1	85.00	90.00	76.92	79.54	76.55	81.60	5.78
	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 (solid fuel used for heating at home)	1	83.33	69.99	88.46	77.49	74.99	78.85	7.21
	65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	100	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Since for each case the inputs to the equation for the percentage of solid fuel use by the migrant population are changed to constants, the cause of the variability within some cases is not clear. It may be in part due to demographic changes as rural agents change to migrant agents, or perhaps as older agents die off and are replaced by younger ones. The next table shows how the model results are compared with predicted results from the solid fuel use equation.

Table 41: Comparison of model and equation outputs for migrant solid fuel use: extreme cases

Case	Years in Beijing	Predicted percentage of solid fuel use (equation)	Agent-based model percentage of solid fuel use (average of 5 runs)	Percent difference between model and predictions
1 (solid fuel used for both cooking and heating at home)	1	100.00	82.96	17.04
	65	57.44	35.49	38.21
	100	0.00	0.00	0.00
2 (solid fuel used for neither cooking or heating at home)	1	24.97	24.97	0.00
	65	0.00	0.00	0.00
	100	0.00	0.00	0.00
3 (solid fuel used for cooking at home)	1	100.00	81.60	18.40
	65	0.00	0.00	0.00
	100	0.00	0.00	0.00
4 (solid fuel used for heating at home)	1	100.00	78.85	21.15
	65	0.00	0.00	0.00
	100	0.00	0.00	0.00

As can be seen from the table above, the model matches the predicted results quite well for extreme cases. The percent difference between the model and predicted outputs ranged from 17.-

4 to 38.21 percent, with the largest difference being for case one and 65 years. The model consistently predicted the 100 year outcome of no solid fuel use, although it did generally under-predict solid fuel use for migrant workers only living in Beijing for one year by roughly 17 to 21 percent.

A similar analysis can be conducted for extreme cases for the rural population within the model. For the rural agents, two extreme cases were run:

1. Affluent Case: in this situation, the location is set to South, the house size and the amount of electricity spent set to their maximum values, and the starting education level for every age range is set to 5. The education rate is also set to high.
2. Poorer Case: in this situation, the location is set to North, the house size and the amount of electricity spent set to their minimum values, and the starting education level for all age ranges is set to 1. The education rate is set to low. Results from five model runs for each are shown below[16]:

Table 42: Results of model runs for extreme cases: rural agents

Case	Model Run					Average	Standard Deviation
	1	2	3	4	5		
1 (Affluent Case)	6.06	5.67	5.27	5.75	5.27	5.60	0.34
2 (Poorer Case)	99.795	99.792	99.795	99.792	99.792	99.79	0.00

The results for case two (the affluent case) remain consistent throughout the five model runs while the affluent case exhibits slight variation. Since most inputs were changed to constant values, it is not clear why there is variability within the affluent case but not in the poorer case. Since rural families would have the option to increase their education level (and affluent ones

16 In this case the number of years was not altered between runs as it is not an input for the percent of solid fuel use for rural families. The model was run for the original 25 years.

not, since they are already at level 5), we might expect variability based on education level for the rural population but this is not what is observed. The table below gives a comparison of the average model outputs with predicted values from the equation for rural solid fuel use.

Table 43: Comparison of model and equation outputs for rural solid fuel use: extreme cases

Case	Predicted percentage of solid fuel use (equation)	Agent-based model percentage of solid fuel use (average of 5 runs)	Percent difference between model and predictions
1 (Affluent Case)	5.27	5.60	6.44
2 (Poorer Case)	99.79	99.79	0.00

Again we see that the model does an excellent job of predicting the percentage of rural solid fuel use for both the extremely affluent and extremely poor case. The ability of this model to predict extreme cases for both migrant and rural populations gives us greater confidence in the validity of the model to predict values in-between these two extremes, and this approach is an excellent method for checking overall model validity.

5.7 Sensitivity Analysis

After calculating results from the Tsinghua Rural Energy Survey and the Beijing Migrant Workers Survey, these results were then used to develop the agent-based model to predict probabilities of solid fuel use for rural China and migrant workers in Beijing over the next 25 years.

Four different scenarios can be evaluated: regional solid fuel use for north and south, in combination with high or low educational rates for migrant workers. Since migrant workers' children are not allowed to attend public school in their new cities, education is a serious concern for these families. By evaluating what would happen if migrant workers had access to higher education it is possible to investigate how a policy change (of increasing education for migrant workers) would have a direct impact on solid fuel use and thus on both public health and environmental impacts. Each combination of inputs was run 10 different times, and mean and standard deviations calculated. This method was based on work by Brown, et al (Brown, Page, Riolo, & Rand, 2004, p. 1107). Results are shown below.

Table 44: Sensitivity analysis of rural population

POPULATION	**RURAL**							
	% Solid Fuels		Income		Education Level		% of Population	
	Avg.	*St. Dev.*	*Avg.*	*St. Dev.*	*Avg.*	*St. Dev.*	*Avg.*	*St. Dev.*
North								
High education rate	94.24	1.04	53593.20	1421.19	3.53	0.11	25.50	2.84
Lower education rate	93.78	0.81	53738.60	2832.70	3.54	0.21	24.20	2.20
South								
High education rate	44.43	4.04	80704.80	5112.84	3.65	0.20	26.40	4.14
Lower education rate	46.36	5.30	79455.50	4530.75	3.59	0.18	24.80	5.18
Totals	69.70	28.08	66873.03	15258.92	3.58	0.06	25.23	0.95

Table 45: Sensitivity analysis of migrant population

POPULATION	**MIGRANT**							
	% Solid Fuels		Income		Education Level		% of Population	
	Avg.	*St. Dev.*	*Avg.*	*St. Dev.*	*Avg.*	*St. Dev.*	*Avg.*	*St. Dev.*
North								
High education rate	18.76	7.35	152633.40	5189.83	3.70	0.19	23.50	2.37
Lower education rate	19.41	6.44	148263.30	5302.27	3.53	0.19	24.80	2.10
South								
High education rate	19.87	6.04	151994.20	5585.46	3.67	0.21	19.20	7.13
Lower education rate	16.99	7.10	147668.50	2330.86	3.51	0.08	23.50	4.65
Totals	18.76	1.27	150139.85	2535.44	3.60	0.09	22.75	2.44

Table 46: Sensitivity analysis of urban population

POPULATION	URBAN							
	% Solid Fuels		Income		Education Level		% of Population	
	Avg.	*St. Dev.*	*Avg.*	*St. Dev.*	*Avg.*	*St. Dev.*	*Avg.*	*St. Dev.*
North								
High education rate	1.38	1.63	265946.00	0.00	4.08	0.17	51.00	2.31
Lower education rate	0.39	0.81	265946.00	0.00	4.07	0.13	51.80	1.75
South								
High education rate	1.33	1.27	265946.00	0.00	4.03	0.11	52.50	2.01
Lower education rate	1.53	1.53	265946.00	0.00	3.98	0.15	51.70	2.21
Totals	1.15	0.52	265946.00	0.00	4.04	0.05	51.75	0.61

5.7.1 Discussion of Sensitivity Analysis

By examining the total averages for each category and the standard deviation of those averages (see the final row for each population set) we can evaluate which inputs have the greatest impact on model outputs. By far, the greatest differences in model outputs are seen for the rural population, where the differences between rural people in the North and South of China are striking. While education rate does not have a large impact on overall income, total incomes do differ greatly among regions, with those in the North making less than in the South. Additionally, percentage of solid fuel use is much higher in the North, as we might expect with the greater heating burden. The rural population is expected to decrease to an average of 25.23 percent, with an average education level of 3.58.

The migrant population does not exhibit a great difference in use of solid fuels based on education rate, but does show a difference in overall education level based on high versus low education rates, as is expected. Migrant workers are predicted to reach an average of 22.75 percent of the population, with an average education rate of 3.60 and an average percent solid fuel use of 18.76. This is much lower than what is predicted for rural areas, but still higher than the urban predicted levels of solid fuel use.

The urban population is predicted to use a very small percentage of solid fuels – just 1.15 percent. Their education level is predicted to be around 4.04, and they are predicted to account for 51.75 percent of the population in average. As expected, there remains a significant urban-migrant-rural income gap, with urban incomes averaging 265,946 rmb per year, migrant incomes averaging 150,140 rmb per year, and rural incomes averaging just 66,873 rmb per year.

5.8 Model Limitations

Limitations of this model include a small sample size in the migrant workers survey, and a need to incorporate more detailed information about urban areas. There is definitely the possibility to incorporate some other factors to increase the richness of the model. Some additional factors to include could be cost of electricity and housing area, since they were identified in the previous analysis to be effective predictors of rural solid fuel use. While good data on housing area may be difficult to find, electricity costs could certainly be incorporated. Other factors that could be included are gender, age, remittances, assets and exposure to indoor air pollution. These are discussed in future detail in the next section.

5.9 Possible Model Expansions

5.9.1 Possible Additional Parameters

Other parameters that could be included to improve the model fall into the categories of numerical inputs and behavioral rules. Numerical inputs help predict outputs and behavioral rules help predict how agents will behave in given situtaions.

Table 47: Possible model expansion factors

Numercial Inputs	Behavioral Rules	Other Outcomes
Gender	Awareness of new technologies	Global warming
Fuel costs	Awareness of health impacts of solid fuels	Climate change
Cost of new technologies (solar hot water, biogas digester, etc)	Renewable energy laws and policies	Burden of disease to due indoor air pollution from solid fuels
Village size	Interest of rural families in trying new technologies, renewable energies	
Renewable energy subsidies	Attitudes towards energy choice in rural and migrant people	
Energy demand	Different predictions for patterns of migration	
Housing type (WWR, ventilation, insulation)		
Availability and access to different fuels		

5.9.1.1 Gender

While this model does not take gender into account, this would be a viable model expansion. Different sources give different estimates of the percentage of migrant workers that are women. While the novel Beijing migrant workers energy survey found that a high percent of respondents are women, that is likely due to the specific location and population sampled (clothing markets within Beijing).

Since development work in general often places an emphasis on empowering, helping, and giving decision-making power in finances to women, modifying the model to take gender into account would help development professionals and national-level policy makers to have a better grasp on the travel patterns of women migrant workers and their specific risk of using solid fuels as they migrate to the cities. This could allow for more effective interventions in the form of health education for this specific group of women.

5.9.1.2 Age and Remittances

Research has shown that age of migrant workers has an impact on the amount of money they are sending home, depending on if they are supporting their own children, supporting their parents, or if they eventually are supported by their own parents: "Age of the migrants has a significant quadratic effect. Among those who remitted, the amount rises with migrant's age, peaks at one point, then decreases. This can be explained by life course progression" (Cai, 2003, p. 479).

5.9.1.3 Linking Assets with Income

As shown in the Beijing migrant workers survey, migrant workers' incomes can be directly correlated with their use of appliances. Since survey respondents often over or under-report their income, one way to validate reported income may be by double-checking it against their reported owned appliances (Sather, 2010). A possible expansion to the model would be to have a component where the users could enter in types of appliances, and the model could report back earned income.

5.9.1.4 Exposure to Indoor Air Pollution

One of the main reasons for seeking to predict solid fuel use by rural families in migrant workers in this model is to use solid fuel use as a stand-in for exposure to indoor air pollution from solid fuels, which is a leading risk factor for disease and causes almost 2 million premature deaths each year.

According to Jin et al, the three aspects that affect a person's exposure to indoor air pollution (IAP) are the source of emissions, their own behavior, and the housing characteristics of where they live and these connect to c_i, t_{ij}, and w_j respectively. The equation for IAP exposure (E) is given below:

$$E = \sum_{i=1}^{n} \sum_{j=1}^{m} w_j t_{ij} c_i$$

where i is a given period of the day with each period equal to one activity; n is the total number of activities; j is the spatial microenvironment; m is the total number of microenvironments; w_j is the conversion factor for the jth microenvironment; t_{ij} is time spent in a particular environment for a particular activity period; c_i is the pollution concentration for that given activity time period. So it is seen that total exposure is summing all exposure during all activities in all locations over all time periods for a given day. (Jin, Ma, Chen, Cheng, Baris, & Ezzati, 2006, p. 3164).

Possible future model expansions would include moving the output from probability of solid fuel use to probability of IAP exposure. In their model, WHO used a ventilation factor of 0.25. Clearly, one number cannot apply to the entire country, and it may be more effective to have a different number for each province, based on family income and education levels. The Tsinghua survey does provide information on housing type, window style, and perceived ventilation/smokiness (which could help estimate housing characteristics), and the model already provides estimates of emissions sources. However, detailed data on the third component of exposure – behavior – would be needed, and this may be the most challenging of the three to obtain. Data from other studies on rural home energy behaviors could be incorporated into the model to predict rural exposure, but since the behaviors would not be from the same families the housing and source predictions were made from, the estimations may not be useful.

CHAPTER 6
CONCLUSIONS

6 Conclusions

This chapter gives an overview of conclusions about this work, including research summary, interpretation of findings, limitations and future work.

6.1 Research Summary

Based in a desire to better understand the socioeconomic and environmental impacts of energy use as millions of people migrate from rural China into the cities, this dissertation sought to answer the following three research questions:

1. What are the key factors involved in how rural Chinese families and migrant workers make their energy choices for home heating and cooking?
2. Can we effectively predict how these factors will affect China's energy consumption patterns over the next 25 years?
3. Will education about renewable energy effect energy consumption patterns?

By creating, administrating and evaluating the novel Beijing Migrant Workers' Energy Survey, analyzing the Tsinghua Rural Energy Survey data set, and incorporating these results into an agent-based model, we are able to predict solid fuel use and income levels for rural, urban, and migrant populations in China over the next 25 years.

Data from the Tsinghua rural energy survey was used to calculate the top factors impacting rural energy use and connections between education and solid fuel use, and income and solid fuel use. Data from the Beijing migrant workers survey was used to evaluate factors impacting fuel use by migrant workers, how their energy use changes when they move to the city, and connections between their education level and solid fuel use, and income and solid fuel use.

Other socioeconomic issues affecting migrant workers were also addressed, such as their desire to have a hukou, location of their children, and their thoughts on living in Beijing. Results from analysis of both data sets were incorporated into a new agent-based model to predict solid fuel use over the next 25 years by rural, urban, and migrant populations.

Major findings were that the top four factors influencing rural fuel use were location, education, yearly amount spent on electricity, and home area. The top factors influencing solid fuel use among migrant workers was the use of solid fuel for cooking and heating back in their home environment and the number of years they had lived in Beijing. Additionally, it was found that understanding of what renewable energy by migrant workers did not have a significant impact on solid fuel use, although overall education level did.

6.2 Interpretation of Findings

An ability to evaluate what are the top predictors of solid fuel use in rural China (price of electricity, home area, education and income) allow us to think more deeply about what would be the most effective sustainable development interventions that would truly allow rural families to change their fuel sources for cooking and heating to non-solid fuels. Knowing that the price of electricity is a key factor in solid fuel use means that perhaps electricity subsides for rural families might encourage them to convert to using electricity for cooking instead of coal. Home area is less easily addressed, but Dr. Yang's work with rural home renovations outside of Beijing has shown that changes to home structure (for example, by adding insulation) can significantly reduce a rural family's demand for coal for winter heating.

Clearly, education and income are intrinsically linked – families with more income are more likely to enable their children to pursue more education, and those with more education are more likely to have more income. However, in the case of migrant workers this cycle is thwarted as migrants are often forced to either leave their children at home to attend school in their hometown, or place them in a low-quality school in the city. In order for the migrant workers of China to truly thrive, their children need to be afforded an education at least on par with those of the urban residents within the same city.

Migrant workers were perceptive about the health impacts of solid fuels, with migrant workers ranking health impact of the fuels as their top influence on energy choice, followed by cost and environmental impact. While specific knowledge of what renewable energy is does not clearly impact solid fuel use, overall education level absolutely does, as does location. Just by moving to the city, migrant workers of the same educational level were roughly half as likely to use solid fuels as when they were back in their hometowns. Additionally, the differences between workers of a middle school, high school, and college education were striking, with those workers with a college level education about half as likely to use solid fuels as those with a middle school level education. This goes to show what an impact education can truly have on a person's live – it really can make the difference between life and death.

Incorporating survey results into a new agent-based model is an effective way to examine socioeconomic factors to predict environmental impacts and personal health impacts from use of solid fuels. This model highlights again the importance of education, the income disparity between urban, rural, and migrant populations, and shows the tremendous changes in the demographics of China that will take place over the next 25 years.

The ability of the model to compare difference educational scenarios shows the vital importance of *hukou* reform. Only by increasing the ability of all its citizens to pursue higher education will China enable everyone to afford cleaner fuels. China's educational policy of preventing migrant workers' children access to education affects solid fuel use and thus environmental and personal health.

6.3 Limitations

This work has several limitations – limited data on migrant workers and their energy use; limited information on urban education, income and energy use; the need for clearer data on rates of educational increase; the possibility of increasing the number of factors incorporated into the model; and model validation.

While 191 surveys of migrant workers were conducted, not all the data was accurate enough to analyze, leaving only 103 useable responses. A larger data set to work with would have been ideal, but there does not appear to be any work on migrant workers in Beijing yet that includes detailed information about fuel use – most studies focus instead on health or other socioeconomic issues.

While access through the University of Colorado to the China Statistical Yearbooks and other province-wide and country-wide data proved useful, access to a particular survey of urban income, education, and energy use was lacking. Analysis of this data could provide more accurate analysis of the urban situation and better comparisons with the rural and migrant populations.

Survey data used for this survey was not longitudinal, so was not able to be used to analyze the rates of educational increases for different populations and regions. However, the China statistical datasets do provide information on percentages of populations at different educational levels through different years so this could be used to enhance the model.

The model can always be enhanced with more and more factors, of course, and some of these possible factors are listed in Chapter 5, including fuel costs and costs of new technologies.

Attempting model validation is challenging, because the rate of migration in the past few years, (and predicted for the next few decades), in China is unprecedented. There is not yet much available data on migration and energy use, and this is an important area of future research in China.

6.4 Applications to Similar Challenges

The issue of migration within China is a unique challenge in the world today. Nowhere else in the world is experiencing the sheer volume of people moving from rural areas to cities and to work in factories the way that China is. However, an understanding of *how* to determine which factors impact solid fuel use within differing populations in a developing country is a powerful tool and could be used in many developing nations and areas. The methods developed in this dissertation could be used in poorer areas where a large percentage of the population are using solid fuels to better estimate the percentage use of solid fuels, and thus the burden of disease on a community or region.

Aspects of the migration-focused part of this agent-based model could possibly be applied for areas that are experiencing high levels of migration, especially for areas with a high refuge population. The International Organization for Migration estimates that 3.1% of the world's population are migrants, 49% of those are women, and that there are 15.4 million refugees in the world today. They also estimate that there are 214 million migrants worldwide, which seems shockingly low compared to the predicted 240 million people expected to migrate within China during the next decade or so (International Organization for Migration).

One especially interesting application of this work may be to the situation faced in refugee camps, where people are displaced from their homes, and are generally low-income. As this research has shown respondent's dependence on using fuels that they are familiar with, it would be interesting to research how behavioral change plays a role within solid fuel use in refugee camps.

6.5 Future Work

There are many ways to enhance and expand this work, four of which are briefly outlined below:

1. Collect a richer data set on migrant workers' energy use
2. Incorporate a greater number of factors into the model
3. Creative educational outreach to migrant workers and their children
4. Expansion of applications to refugee camp populations

One powerful way to enhance this specific work would be to obtain a richer migrant workers data set. Collection of a much greater data set on energy use among migrant workers in Beijing (and other cities such as Shenzhen, Shanghai or in Guangdong) would provide a richer evaluation of how migrant workers use energy and how this differs from their energy use in their hometowns. A detailed before-after comparison of energy use and types, and especially an evaluation of how the remittances that migrant workers send home affect energy use in their hometowns, would be useful in understanding how migration affects overall energy use.

An additional improvement would be to incorporate a greater number of factors (such as fuel costs) into the model, which could make it more useful for development professionals who are interested in the impacts of different factors on sustainable development and fuel use. This would also provide the ability to assess different policy scenarios (such as rates of education, the number of people who can attend college, and revocation of the hukou system) could increase its usefulness to policy makers and those interested in educational policy in China.

Expansion of this work into further areas could include a focus on education among migrant adults and children. This work has shown that there is a direct correlation between the fuel types migrant workers used at home, and what they are currently using, even in the capital city of China. It also has shown that there are direct connections between education, income, and solid fuel use. However, China's restrictive policies on education for migrant workers' children may prevent migrant children from obtaining a good education. A multi-pronged educational approach, including focus groups, children's educational programs, and adult educational outreach could serve to educate adults and children about cleaner energy alternatives to solid fuels.

Lastly, the ability to survey a low-income population and use survey responses to predict percentage of solid fuel use could be used in a refugee population who may be trying to transition from one fuel source in their home community to another used within a refugee camp or new location. Some engineering groups are working to introduce fuel-saving stoves and techniques into developing countries and into refugee camps and an in-depth analysis of the challenges involved with such a technology and behavioral change could have useful public health and development implications.

China is changing so rapidly, and it's hard to imagine that anyone can even come close to predicting what will actually happen in the next few decades. I am grateful for the chance to think deeply about these issues and conduct my own research in such a special nation. I consider it a great privilege to have spent more than two and a half years living in Beijing and conducting research throughout China, and I am deeply thankful for the chance to interact with rural families and migrant workers. I am forever indebted to them for their graciousness to me.

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